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Eagle RTS:

A Design for a Regional Transport Aircraft

A design project by students in the Department of Aerospace Engineering at Auburn University, Auburn, Alabama, under the sponsorship of NASA/USRA Advanced Design Program

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Abstract

The Eagle RTS (Regional Transport System) is a 66 passenger, twin turboprop aircraft with a range of 836 nautical miles. It will operate with a crew of two pilots and two flight attendants. This aircraft will employ the use of aluminum alloys and composite materials to reduce the aircraft weight and increase aerodynamic efficiency. The Eagle RTS will use narrow body aerodynamics with a canard configuration to improve performance. Leading edge technology will be used in the cockpit to improve flight handling and safety.

The Eagle RTS propulsion system will consist of two turboprop engines with a total thrust of approximately 6300 pounds, 3150 pounds thrust per engine, for the cruise configuration. The engines will be mounted on the aft section of the aircraft to increase passenger safety in the event of a propeller failure. Aft mounted engines will also increase the overall efficiency of the aircraft by reducing the aircraft's drag.

The Eagle RTS is projected to have a takeoff distance of approximately 4700 feet and a landing distance of 6100 feet. These distances will allow the Eagle RTS to land at the relatively short runways of regional airports.

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List of Symbols

<u>Symbol</u>	<u>Definition</u>	<u>Units</u>
AR	Aspect ratio	-
b	Span	ft
c	Chord length	ft
C_D	Coefficient of drag	-
$C_{D\alpha}$	Coefficient of drag due to angle of attack	-
C_{Dp}	Coefficient of parasitic drag	-
C_{Du}	Coefficient of drag due to Mach number	-
C_M	Moment coefficient	-
$C_{M\alpha}$	Moment due to angle of attack	-
$C_{M\alpha f}$	Moment due to angle of attack on fuselage	-
$C_{M\dot{\alpha}}$	Moment due to rate of change of angle of attack	-
C_{Mq}	Moment due to pitch rate	-
C_L	Coefficient of lift	-
C_{Lu}	Coefficient of lift due to Mach number	-
$C_{L\alpha}$	Coefficient of lift due to angle of attack	-
$C_{L\alpha t}$	Coefficient of lift due to angle of attack of tail	-
$C_{L\alpha w}$	Coefficient of lift due to angle of attack on wing	-
C_{Lt}	Coefficient of lift on tail	-
$C_{L\beta}$	Coefficient of lift due to sideslip angle	-
e	Oswald's efficiency factor	-
E	Endurance	hrs
ϵ_o	Downwash angle	degrees
γ	Flight path angle	degrees
g	Force of gravity	ft/sec ²
Γ	Dihedral angle	degrees
i_t	Incidence angle on the tail	degrees
I_y	Moment of inertia about y-axis	lb-s/ft ⁴
l	Length of the wings relative to centerline	ft
$M_u, M_w, M_{\dot{w}}, M_q$	Moments	-
μ	Rolling coefficient	-
η	Propeller efficiency	percent
n_{max}	Load factor at maximum	-
ξ	Frequency	rad/s
ϕ	Turn angle	degrees
R	Range	nmiles
R	Radius of turn	ft
RC	Rate of climb	ft/min
RD	Rate of descent	ft/min
ρ	Atmospheric density	lb-s ² /ft ⁴
q	Dynamic pressure	lb/ft ²

<u>Symbol</u>	<u>Definition</u>	<u>Units</u>
S	Reference area	ft ²
S ₅₀	Distance from approach to contact	ft
S _G	Distance of ground roll	ft
S _T	Total distance	ft
Ψ	Turn rate	deg/sec
T _s	Static thrust	lb
T	Thrust	lb
THPreq	Thrust horsepower required	hp
THPav	Thrust horsepower available	hp
V	Velocity	ft/s
V _C	Velocity at point of contact	ft/s
V _B	Velocity at point of braking	ft/s
V _{CL}	Velocity at climb	ft/s
V ₅₀	Velocity at h=50 ft obstacle	ft/s
V _{TO}	Velocity at takeoff	ft/s
V _H	Horizontal tail volume	ft ³
W	Weight	lb
X _{cg}	Location of center of gravity	ft
X _{ac}	Location of aerodynamic center	ft
X _{np}	Location of neutral point	ft
X _u , X _w , X _w , X _q	X-Force coefficients	-
Z _u , Z _w , Z _w , Z _q	Z-Force coefficients	-

Introduction

The Eagle RTS (Regional Transport System) is a 66 passenger aircraft designed to satisfy the need for accessible and economic travel. The primary function of this aircraft is to provide small and medium sized cities with a quality air transportation service. The need for this regional aircraft stems from the hub airport congestion. This service will allow a passenger to travel from one spoke city to another spoke city without entering the congested hub city airport. It also allows those people traveling longer routes to begin the flight at home instead of traveling by automobile to a hub airport.

The number one design objective for the Eagle RTS will be safety. This aircraft will be safer because it avoids the hub air traffic congestion. Another safety consideration involved in the design is the anti-stall characteristic of the aircraft due to tailoring of the canard. The location of the propulsion system is also a factor in safety. The propulsion system on the Eagle RTS is placed on the aft section of the aircraft so that in the event that a blade is shed, it will not affect the passenger compartments or the major control surfaces. These safety considerations will make this aircraft a safer flight vehicle than most aircraft today.

In trying to provide the most economical and commercial flight system available, the Eagle RTS design team plans to employ the use of existing technology which will lower production and maintenance costs. This practice will reduce labor and crew costs by decreasing the amount of new training required. In selecting the propulsion system, the effects of the environment were also considered. Two advantages of turbo-prop engines are the high fuel efficiency and low noise levels produced by this type of engine.

In order for the Eagle RTS to fly spoke-to-spoke, it must be capable of landing on shorter runways. It also must have speeds comparable to that of the larger aircraft to make its service beneficial to the airlines. The Eagle RTS will cruise at 260 knots at an altitude of 25,000 feet. The aforementioned factors of safety, speed, comfort, and airport flexibility will make the Eagle RTS economically competitive in the commercial aircraft market.

I. Aerodynamics

The body shape is an elongated “teardrop” shape with pusher engines located behind the sweptback wings. This configuration will allow for minimum body drag while allowing for maximum flexibility in designing the interior arrangement. Figure 1.1 provides a three-view and Figures 1.2-1.4 provide the side, top and front views of the Eagle RTS.

The airfoil selected for the Eagle RTS is the NACA 63₂-615 series airfoil. This airfoil was selected because it had the most efficient cruise characteristics. The NACA 63₂-615 airfoil has a high stall angle of attack. Also, as this airfoil approaches the stall angle it goes into a ‘soft’ stall as opposed to an abrupt stall. According to Daniel P. Raymer the recommended wing thickness ratio for twin turbo prop aircraft is 0.14 ⁽¹⁾.

The Eagle RTS uses a compound wing design shown in Figure 1.5. The sweep angles for this wing are 9° and 60°. These angles were chosen to provide a wing area which produced a maximum lift coefficient and a minimum wing loading while also providing excess fuel tank storage. The wing loading is calculated to be 70 lb/ft². Figure 1.6 provides a plot of the lift coefficient versus the angle of attack.⁽²⁾

The drag polar was calculated using Roskam’s Methods for Estimating Drag Polars of Subsonic Airplanes ⁽³⁾ which was done through the use of a FORTRAN language program as seen in Appendix A.

$$C_{D \text{ cruise}} = 0.0615$$

Figure 1.7 provides a plot of the drag coefficient versus the lift coefficient.

The Eagle RTS will employ the use of a canard. The purpose of this canard is to prevent stall characteristics such as spin and uncontrolled roll. The canard airfoil selected for the Eagle RTS is the NACA 0009 series. A detailed dimensional layout of this canard may be seen in Figure 1.8. The main wing will cruise at an angle of attack of 1°. Also the main wing has a zero lift angle of attack of -5° and a stall angle of attack of 12°. To choose the proper canard to prevent aircraft

Eagle RTS

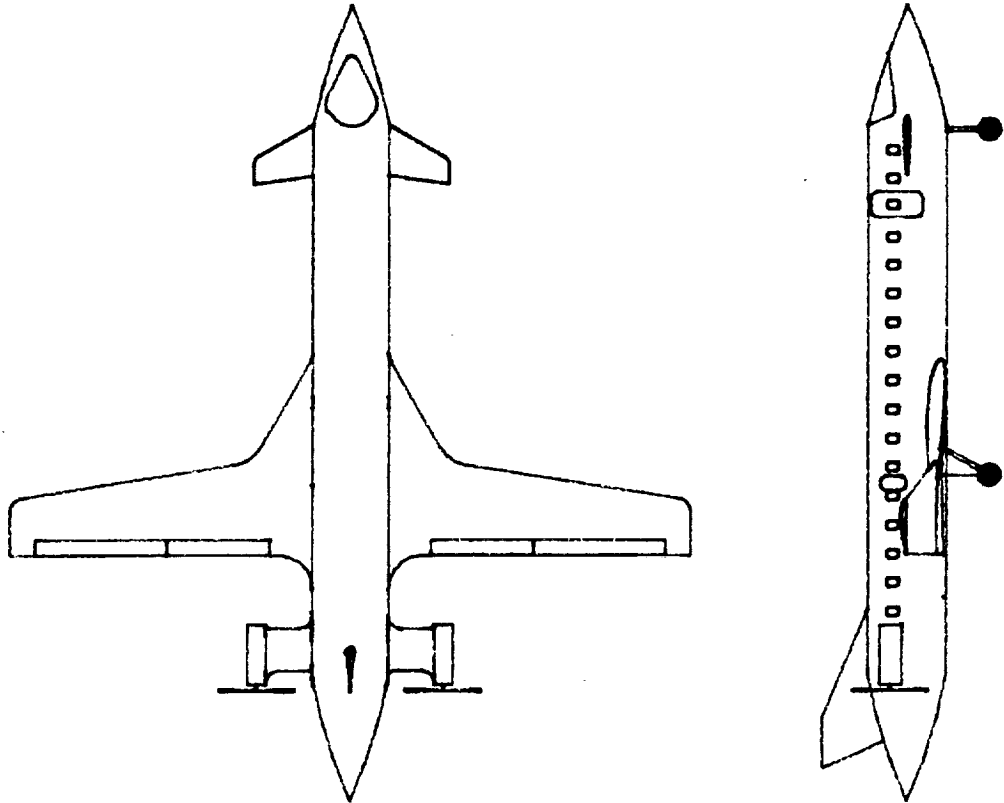


Figure 1.1 Three View of the Eagle RTS

Eagle RTS Side View

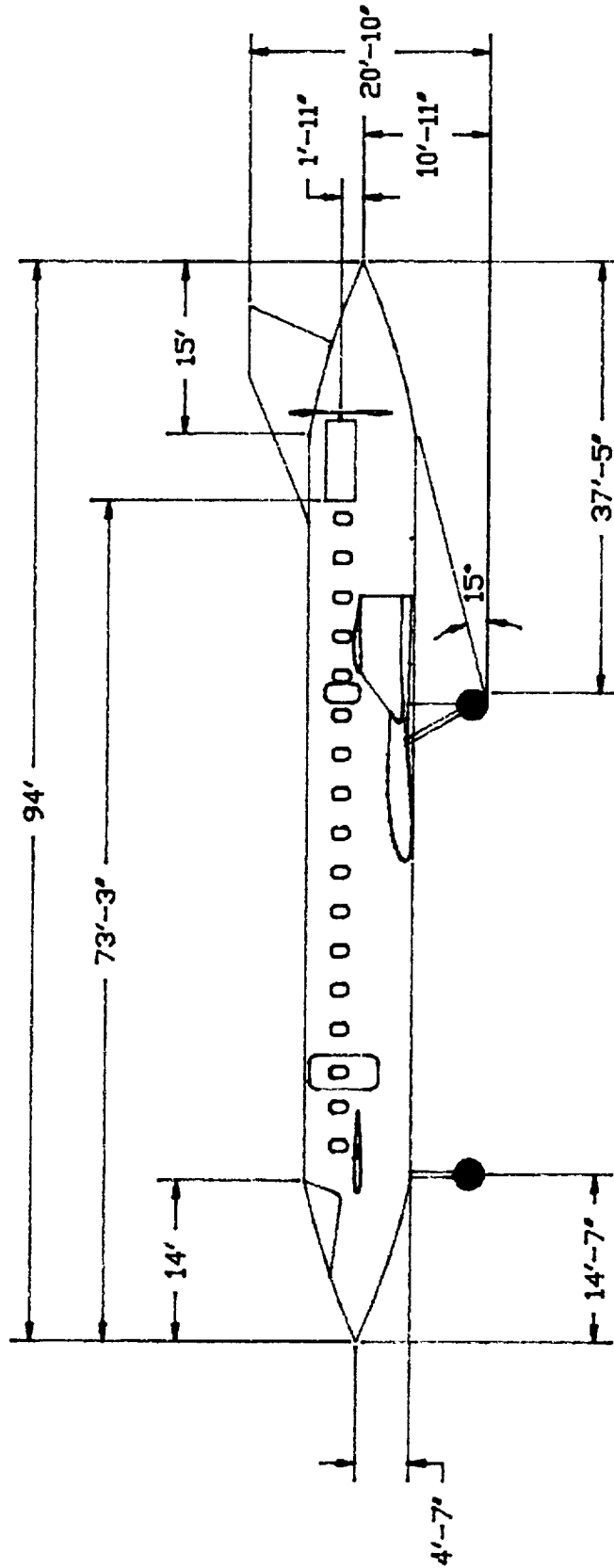


Figure 1.2 Side View of the Eagle RTS

Eagle RTS

Top View

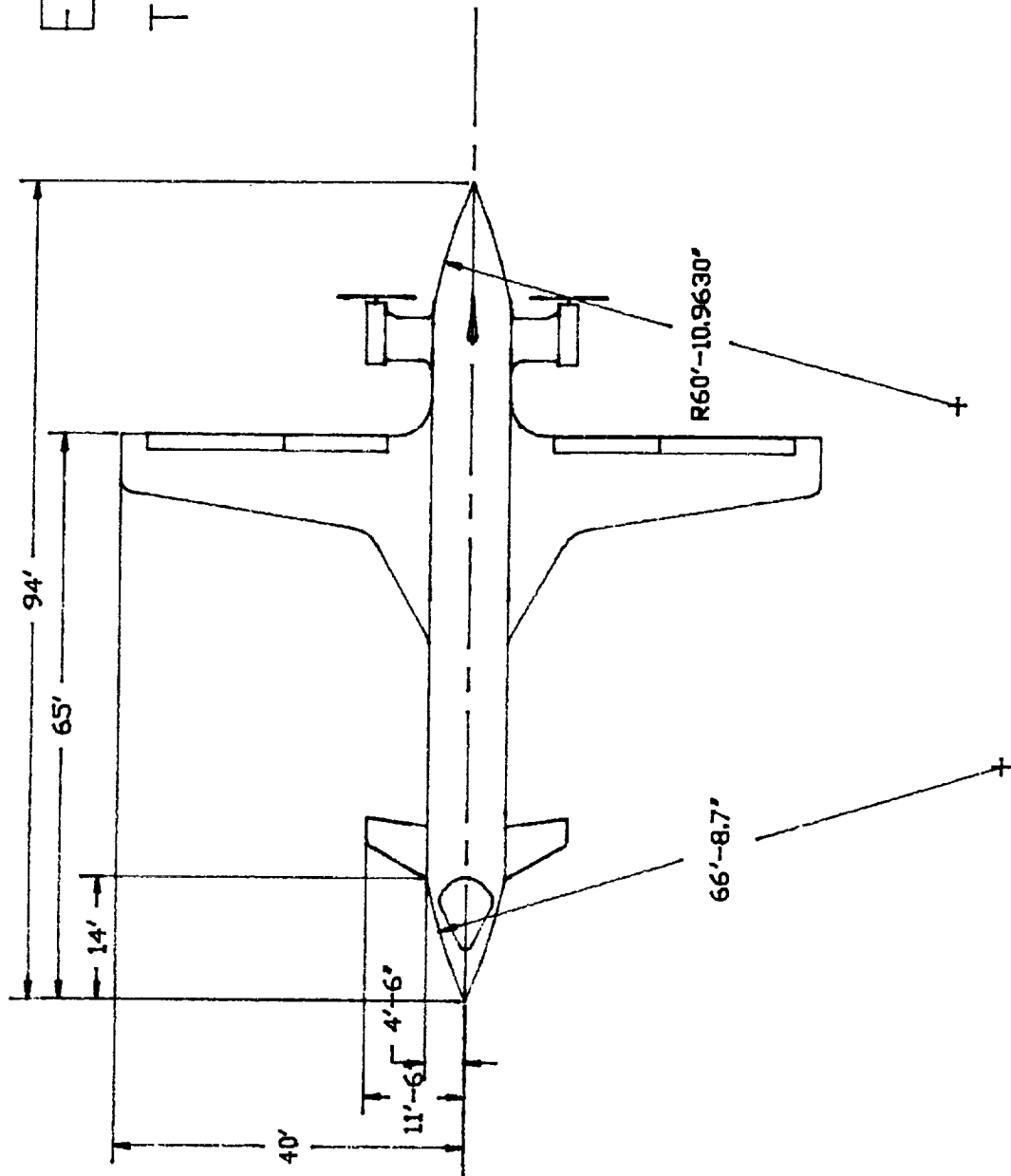


Figure 1.3 Top View of the Eagle RTS

Eagle RTS Front and Rear Views

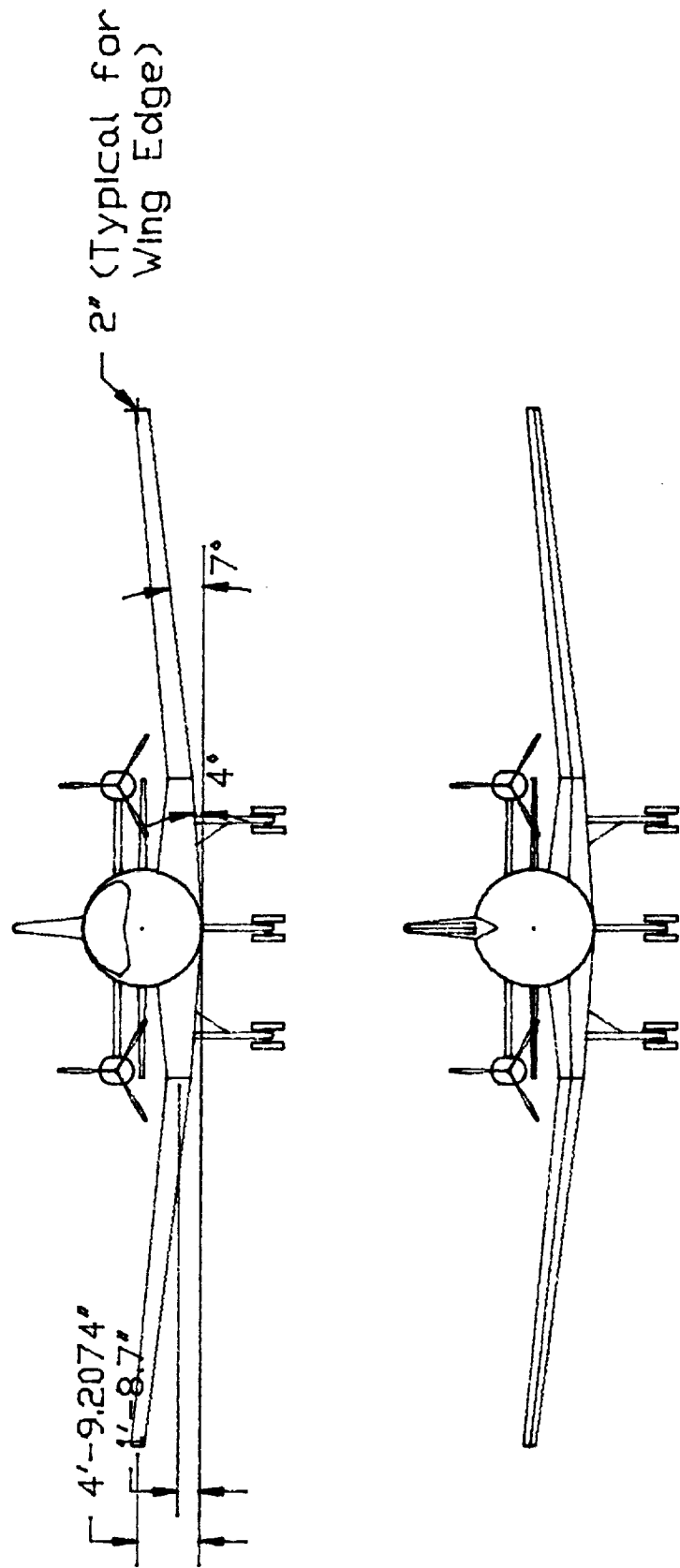


Figure 1.4 Front and Rear View of the Eagle RTS

Eagle RTS

Wing Reference Area

Reference Area = 986.68 sq. ft.

- only half total area shown

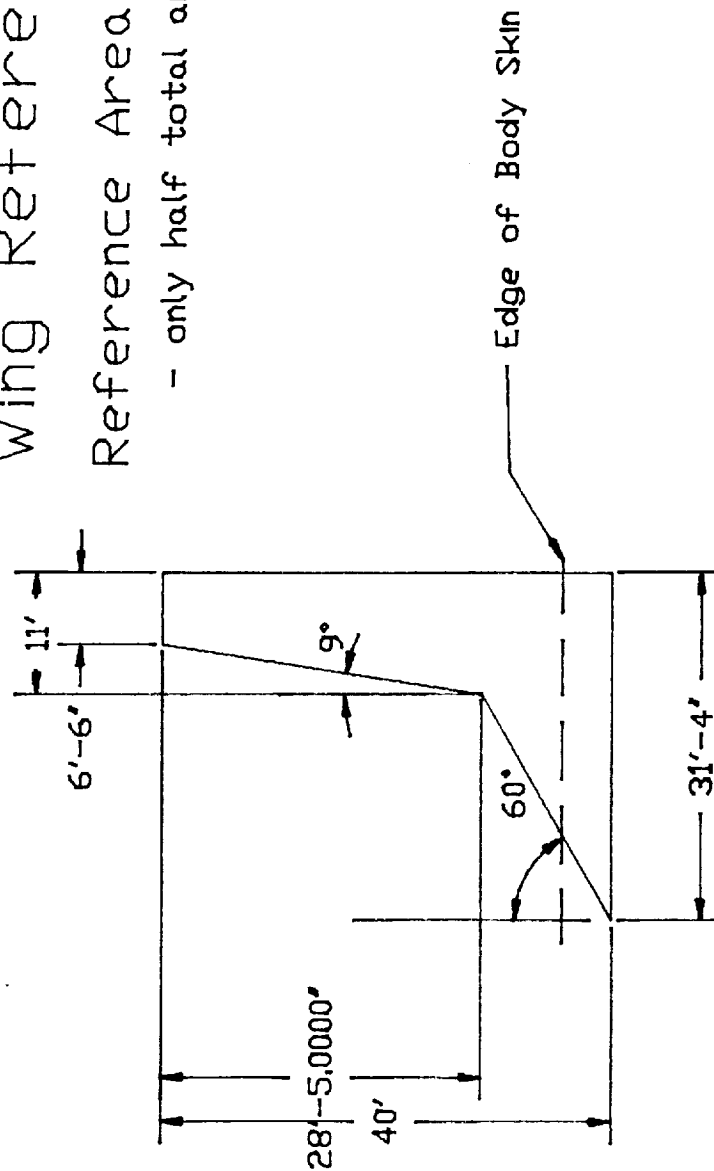


Figure 1.5 Compound Wing Design

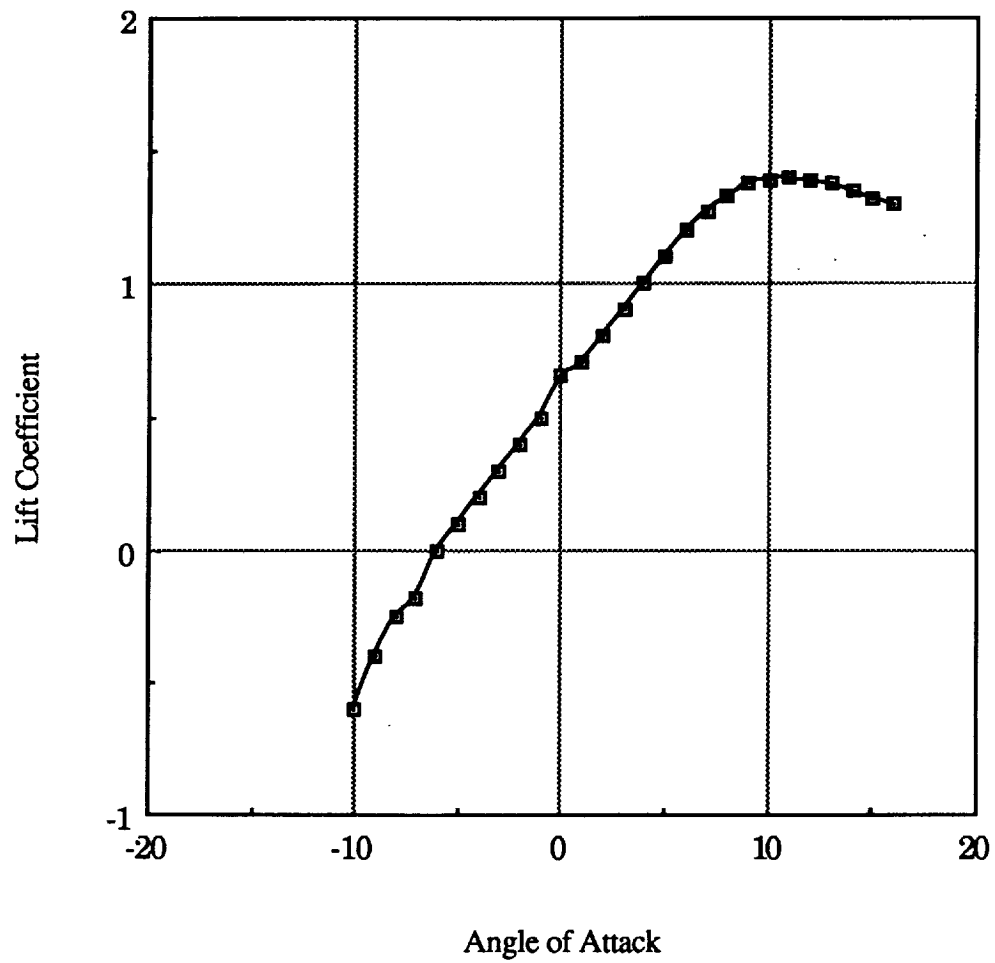


Figure 1.6 Aircraft Lift Coefficient vs. Angle of Attack

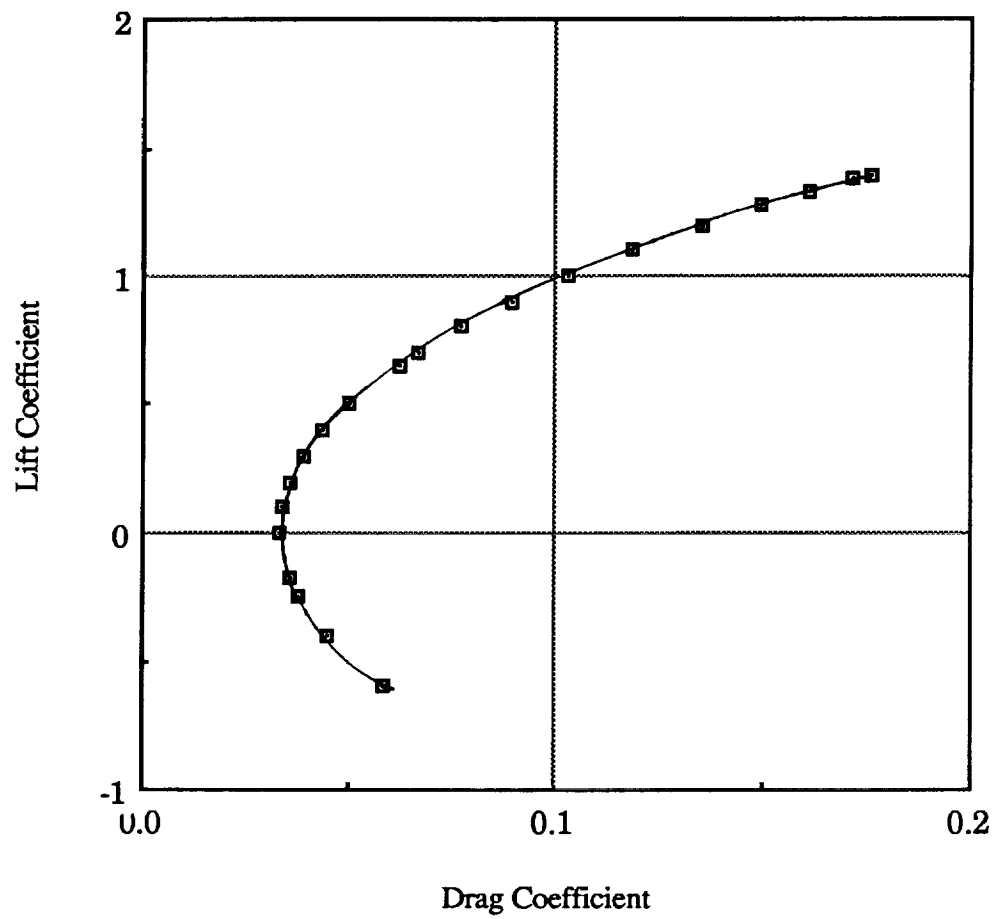


Figure 1.7 Lift Coefficient vs. Drag Coefficient

Platform Area = 62,734 sq. ft.
- only half of area shown

Figure 1.8 Canard Detail

stall this canard must have a stall angle below that of the main wing. The canard for the Eagle RTS will cruise at an angle of attack of 2° while stalling at an angle of attack of 9° plus or minus 1° . Because the canard will stall at 9° the main wing will never reach its stall angle of attack of 12° (4).

A secondary advantage of the canard for the Eagle RTS is that the canard will eliminate the negative lift normally associated with a tailplane configuration. Also, a canard has a more rapid response time to control input than a tailplane configuration. One disadvantage of a canard is the effect of trailing vortices on the main wing aerodynamics and the engine efficiency. Although these actual effects are still being researched, according to Daniel P. Raymer the most efficient way to minimize these effects is to place both the main wing and engines as far aft and above the canard as possible; which has been done for the Eagle RTS (1).

The tail section for this aircraft uses a vertical tail configuration, NACA 0009 series, which will provide the Eagle RTS with directional stability. The design of this tail uses an area determined from Equation 1.1.

$$S_{VT} = c_{vt} b_w S_w / L_v \quad (1.1)$$

This equation, provided by Raymer, uses a constant (c_{vt}) of 0.08 for twin turboprop aircraft, wing span and wing reference area divided by the distance from the vertical tail to the mean aerodynamic center (L_v) to determine the vertical tail area (1). Figure 1.9 provides a detailed dimensional layout of the vertical tail.

Another important factor in the design is the efficiency of this aircraft, also known as Oswald's efficiency factor. This factor depends on the aspect ratio which is calculated using Equation 1.2,

$$AR = b^2 / S \quad (1.2)$$

where the aspect ratio is a function of the square of the wing span divided by the reference area.

The aspect ratio for the Eagle RTS is 6.5. From this aspect ratio and a parasite drag (C_{Dp}) of 0.032

Eagle RTS Vertical Tail

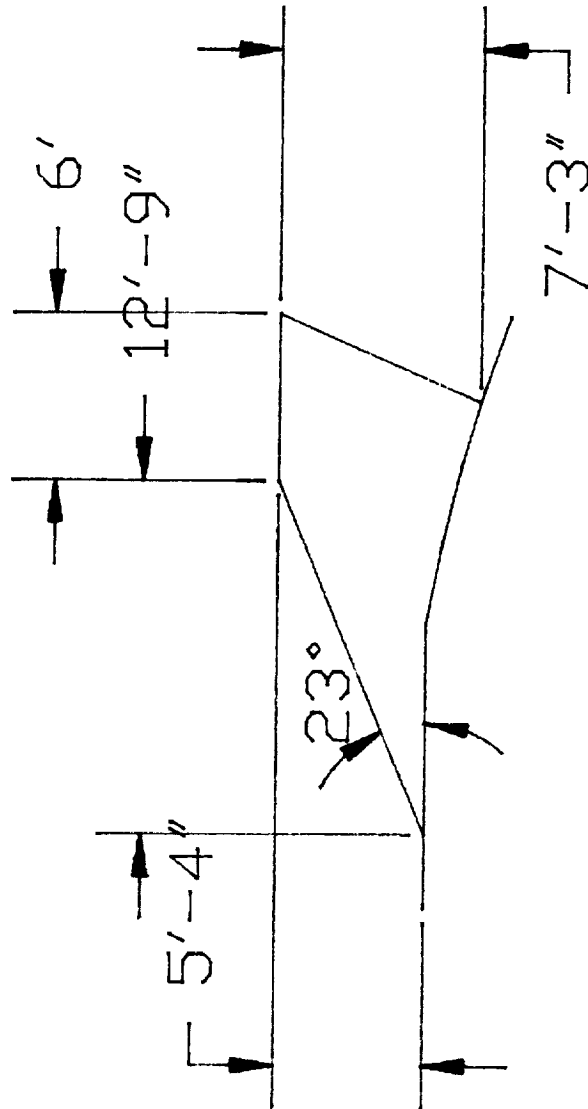


Figure 1.9 Vertical Tail Configuration

the airplane efficiency factor, from Figure 1.10, is found to be 0.775. According to Richard S. Shevell an efficient aircraft operates between an Oswald's efficiency factor of 0.75 and 0.9 (5).

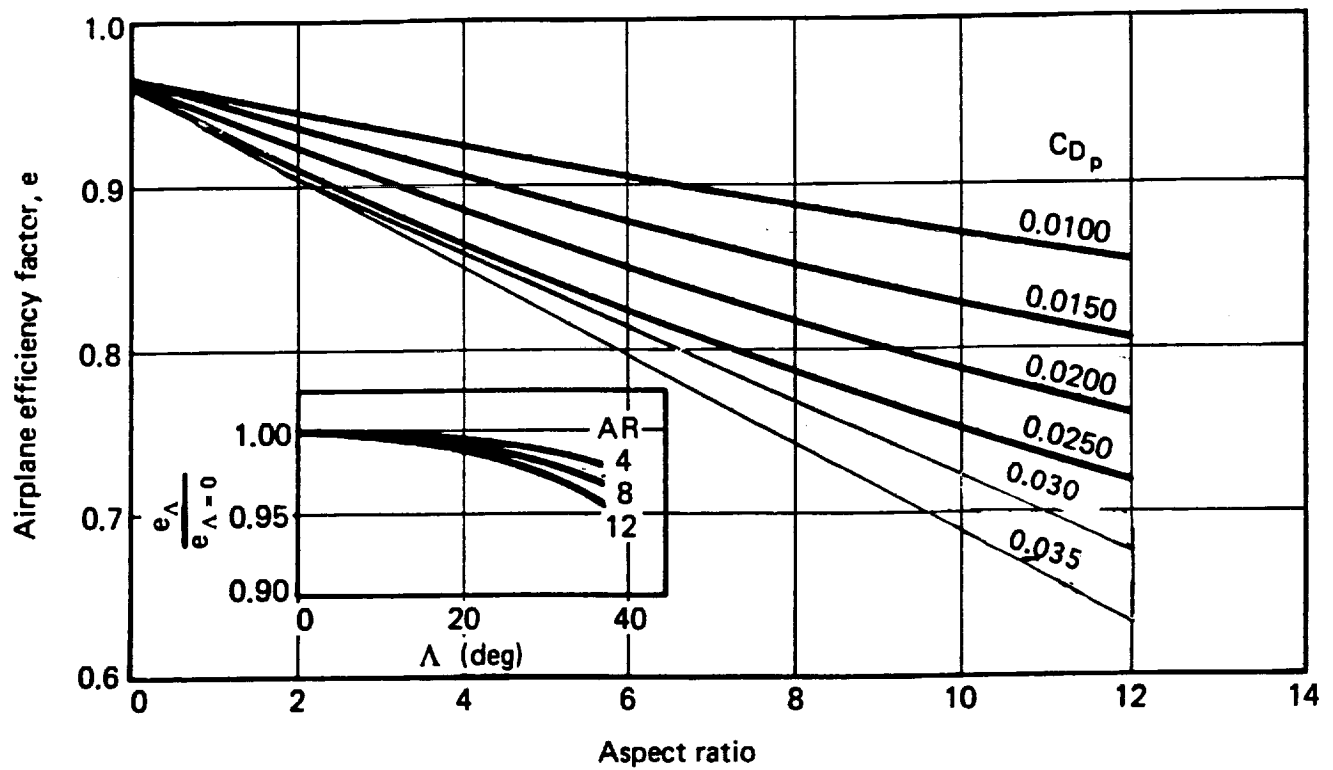


Figure 1.10 Airplane Efficiency Factor

II. Performance Analysis

The first and probably most important consideration in conducting the performance analysis is to determine the thrust needed. Reference material is from references 5,9 and 11. All values used in performance calculations are found in Tables 2.1 and 2.2 and the equations used are

$$\begin{aligned} \text{THP}_{\text{req}} &= \frac{(\text{Drag})(\text{Velocity})}{550 \text{ ft-lb/s}^2} \\ \text{THP}_{\text{av}} &= \frac{(\text{Thrust})(\text{Velocity})}{550 \text{ ft-lb/s}^2} \end{aligned} \quad (2.1)$$

These equations calculate horsepower required and available for the aircraft.

Another important factor in aircraft performance is the rate of climb. To determine the rate of climb in feet per minute:

$$\text{RC} = (\text{THP}_{\text{av}} - \text{THP}_{\text{req}}) 33000 / W \quad (2.2)$$

The rate-of-climb versus velocity is shown in Figure 2.1. Our rate-of-climb at cruise velocity and an altitude of 25000 ft and full passenger and fuel load is 928 ft/min which is not bad for an airplane our size. The opposite consideration to the rate-of-climb is the rate-of-descent. It follows along with the logic of the climb rate and is mainly determined by the flight path angle (γ):

$$\begin{aligned} \sin \gamma &= \text{Drag}/\text{Weight} \\ \text{RD} = V \sin \gamma &= [(2WC_D^2/C_L^2 \cos^3 \gamma)/\rho S]^{0.5} \end{aligned} \quad (2.3)$$

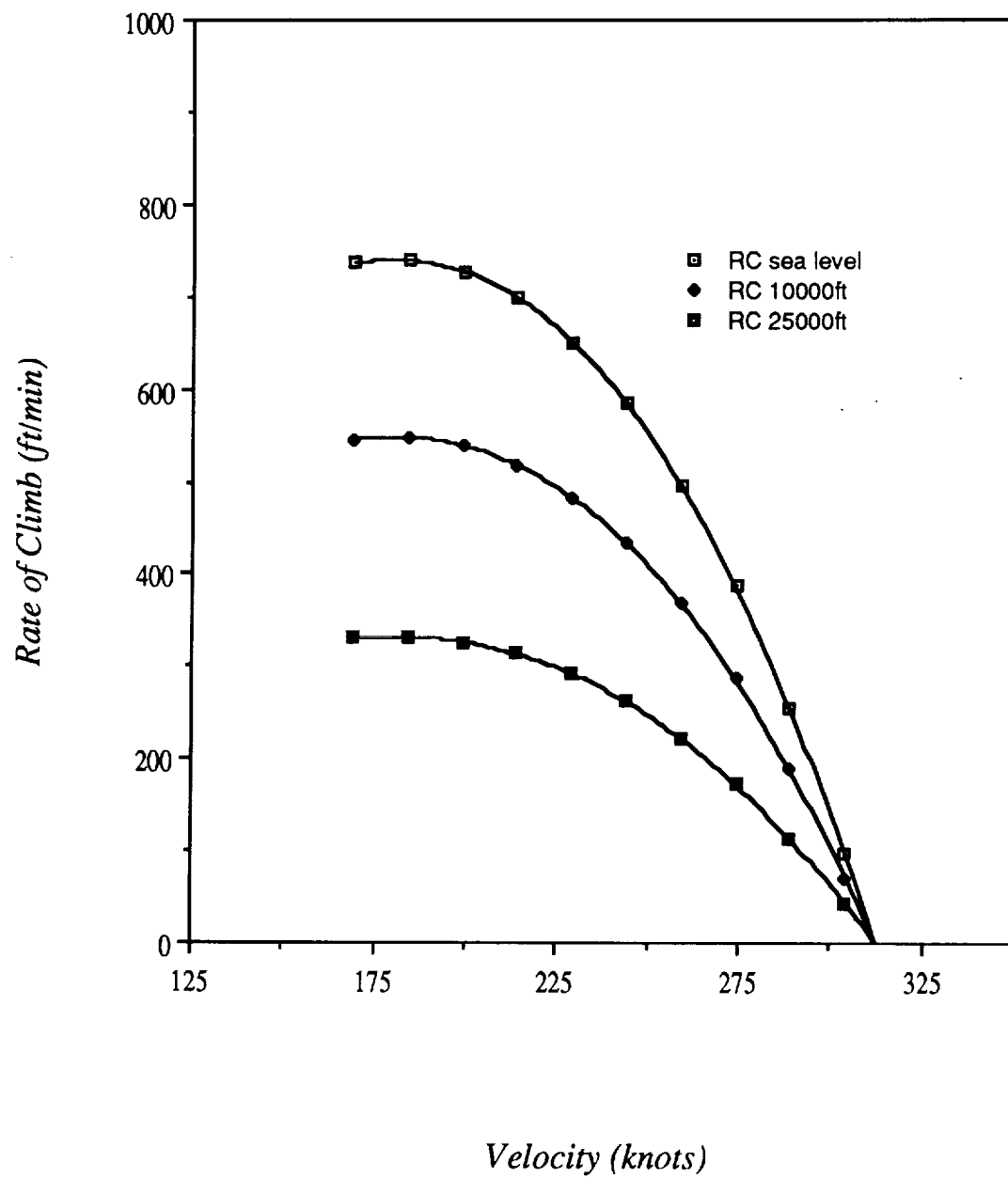


Figure 2.1: Rate of Climb vs. Velocity

Table 2.1: Performance Parameters at Cruise Velocity

Airplane Characteristics:

$W_{oper}=58688 \text{ lb}$

$S=986.68 \text{ ft}^2$

$b=80 \text{ ft}$

$C_D=0.062$

$V_H=0.00853$

altitude=25000 ft

$THP_{cruise}=6300 \text{ hp}$

$C_L=0.386$

$c=14.9 \text{ ft}$

$V_{cruise}=260.5 \text{ knots}$

$W_{ldg}=46408 \text{ lb}$

$THP_{req}=3413.78 \text{ hp}$

$RC=928 \text{ ft/min}$

Range=836.0 nmi

$S_{TO}=4696.4952 \text{ ft}$

$n=1.01223$

$\psi=0.66 \text{ }^\circ/\text{s}$

$V_{flight \text{ path}}=441.3 \text{ ft/s}$

$THP_{av}=5355.0 \text{ hp}$

$RD=2135.7 \text{ ft/min}$

Endurance=2.55 hrs

$S_{Tldg}=6100.0 \text{ ft}$

$\phi=8.92^\circ$

Radius=38307 ft

Table 2.2 Performance Calculations and Constants

Constants:

$L_{\max}=69887.2 \text{ lb}$	$D_{\text{TO}}=10579.4 \text{ lb}$	$S=986.68 \text{ ft}^2$
$(C_L/C_D)_{\max}=9.2124$	$(C_L/C_D)_{\max}^{3/2}=15.5344$	$T_s=12617.34 \text{ lb}$
$T_{\text{TO}}=18438.04 \text{ lb}$	$W=58688 \text{ lb}$	$\mu=0.02$
$V_{\text{TO}}=186.05 \text{ ft/s}$	$V_{\text{CL}}=202.96 \text{ ft/s}$	$V_{50}=219.87 \text{ ft/s}$
$V_C=194.5 \text{ ft/s}$	$V_B=155.6 \text{ ft/s}$	$W_{\text{ldg}}=46408 \text{ lb}$
$\mu_b=0.3$	$C_{L\max}=3.9$	$V_{\text{stall}}=100.15 \text{ knots}$

Takeoff:

$$F_S = T_S - \mu W = 11443.58 \text{ lb}$$

$$F_{\text{TO}} = T_{\text{TO}} - D_{\text{TO}} - \mu(W - L_{\text{TO}}) = 6684.88 \text{ lb}$$

Landing:

$$F_S = T + \mu_b W = 11443.58$$

$$F_C = T + D_{Vc} + \mu(W - L) = 13740.302$$

$$F_{B1} = T + D_{Vb} + \mu(W - L) = 13387.112$$

$$F_{B2} = T + D_{Vb} + \mu_b(W - L_{Vb}) = 25432.38$$

In the initial analysis it was estimated that the range would be 1000 nmi. The range depends on the propeller efficiency, the specific fuel consumption, lift/drag, and weight. To find the maximum range, we use a maximum lift to drag ratio. The equation that is used to calculate range in nautical miles is:

$$R = 325(\eta/c) (L/D) \ln(W_i/W_f) \quad (2.4)$$

Using an efficiency of 0.8 and an SFC of 0.547 lb/hr-HP the range turns out to be 836 nmi. This is below what was specified at the beginning of the design process. However, the range of this airplane will enable it to fly reasonably long distances and is deemed to be adequate.

Takeoff & Landing Performance

The FAR regulations governing the takeoff and landing performance of commercial aircraft is listed below:

Table 2.3

<u>FAR Takeoff & Landing Guidelines</u>		
Velocity:	$V_{TO} \geq 1.1 V_{Stall}$ $V_{CL} \geq 1.2 V_{Stall}$	$V_{50} = 1.3 V_{Stall}$ $V_C = 1.15 V_{Stall}$
Climb:	Gear down $1/2\% V_{TO}$ Gear up $3\% V_{TO}$	
Field Length:	115% takeoff distance over 35 ft obstacle	

Using the equations:

$$S1 = [(W - V_{to}^2) / (2g F_s - F_{to})] \ln (F_s / F_{to})$$

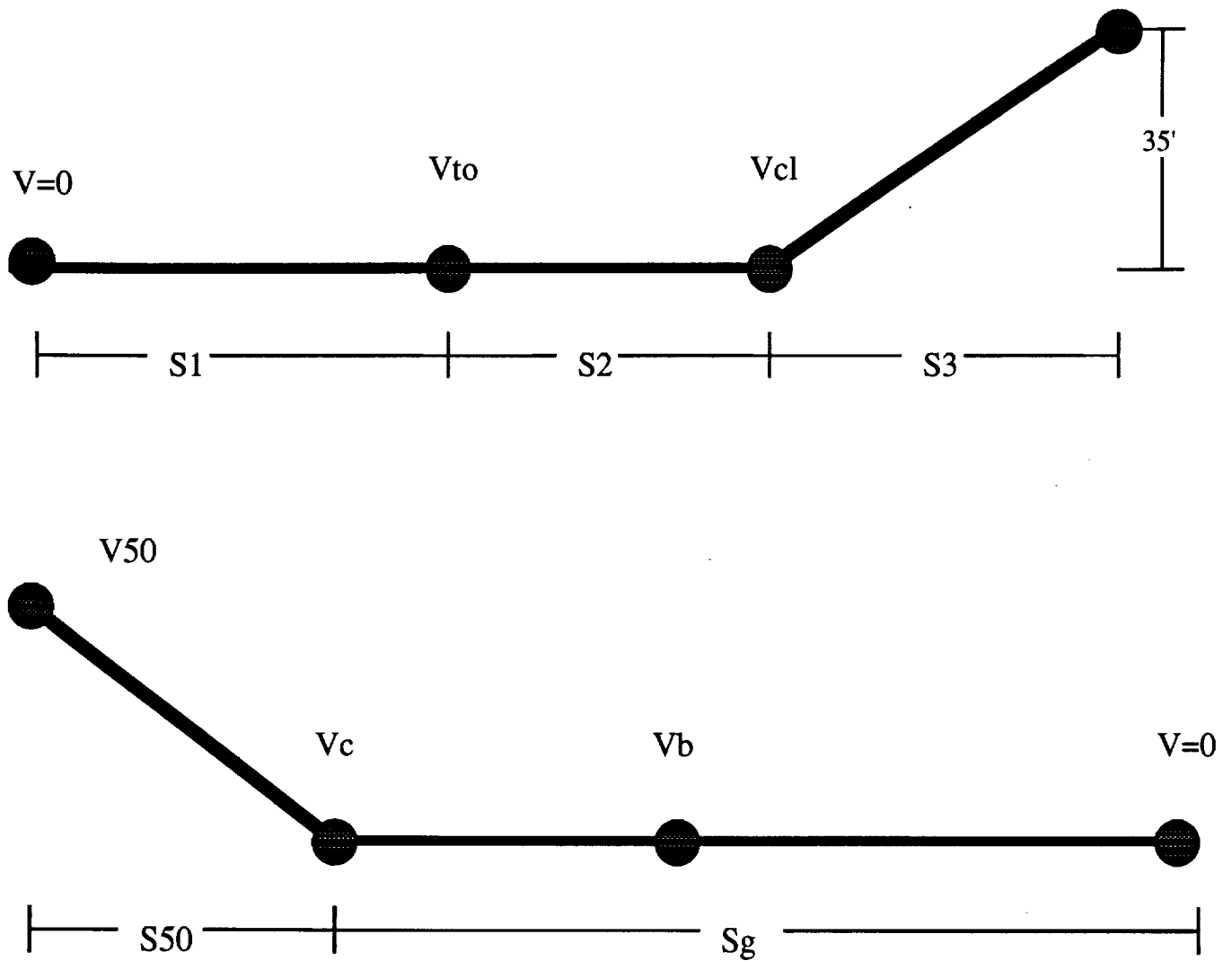
$$S2 = (W/2g) [(V_{cl}^2 - V_{to}^2) / (T_{to} - D_{to})]$$

$$S3 = H \sqrt{(W/T_{to} - D_{to})^2 - 1} \quad (2.5)$$

it was found that the total takeoff distance required was 4700ft. See Figure 2.2 for a breakdown of takeoff and landing distances. Since this airplane is designed to operate from smaller airports as well as larger ones, the landing and takeoff distances must be reasonably short to handle the average runway. To calculate the landing distance required we use the equation below with values of forces and other parameters found in Table 2.1. First start with the distance required to clear a fifty foot obstacle on approach to the contact point on the ground. This is found by:

$$S_{50} = (L/D) [(V_{50}^2 - V_C^2) / 2g + 50] \quad (2.6)$$

By using equation (2.6) in conjunction with this next equation which is ground roll distance measured from the contact point to the braking point and zero velocity (stopping) point;



Takeoff Parameters:

$V_{TO}=186.05 \text{ ft/s}$
 $S_1=3563.64 \text{ ft}$
 $S_{TO}=4696.4952 \text{ ft}$

$V_{CL}=202.96$
 $S_2=762.82 \text{ ft}$

$S_3=370.04 \text{ ft}$

Landing Parameters:

$V_{50}=219.87 \text{ ft/s}$
 $S_{50}=1964.44 \text{ ft}$
 $S_{TL}=3684.063 \text{ ft}$

$V_C=194.5 \text{ ft/s}$
 $S_G=1719.623 \text{ ft}$
 $S_{TL \text{ commercial}}=6140.0 \text{ ft}$

$V_B=155.6 \text{ ft/s}$

Figure 2.2 Takeoff and Landing Breakdown

$$S_G = W/2g \{ (V_C^2 - V_{B2}^2) / (F_{B1} - F_C) \ln(F_{B1}/F_C) + V_{B2}^2 / (F_S - F_{B2}) \ln(F_S/F_{B2}) \} \quad (2.7)$$

Add these two together to get the total landing distance.

$$S_T = S_{50} + S_G \quad (2.8)$$

Our total landing distance is 3700 ft which is roughly two thirds our takeoff distance. Using FAR requirements for a commercial aircraft the landing distance becomes 6100ft. With the addition of ground spoilers this landing distance will decrease. This is well within limits of the runway requirements for our airplane.

III. Stability Analysis

Longitudinal Stability:

In conducting a stability analysis, several features of this field were investigated to determine if the airplane was stable or not. This includes a comparison of pitching moment versus angle of attack, neutral point location and the stability margin. When speaking of stability, it is in reference to longitudinal stability where the airplane has a restoring moment about the center of gravity when disturbed from its equilibrium position. This is normally described by the term Cm_{α} .

For static stability the Cm_{α} must be negative in order to bring the plane back to equilibrium after a disturbance. Each surface on the airplane has a contribution to Cm . The surface with the most impact is the wings. The equation for finding its total value is

$$Cm_{\alpha} = C_{L\alpha w}(X_{cg}/c - X_{ac}/c) \quad (3.1)$$

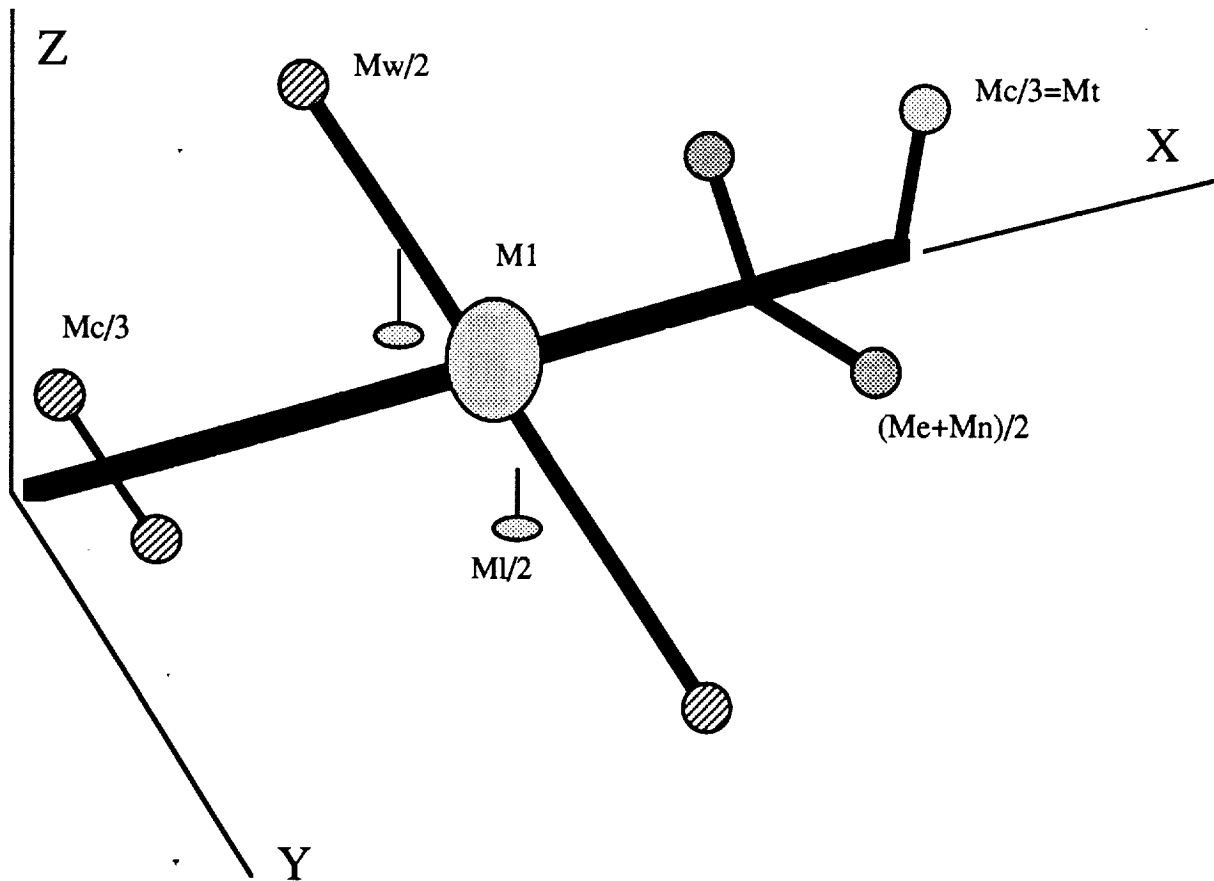
In order to find this value of Cm_{α} and subsequently the variation of it with angle of attack, the neutral point or static margin and center of gravity must be found. Table 3.1 shows the component weights and locations to find the center of gravity location for various loading conditions.

All methods in this analysis are from references 5,9 and 11. Table 3.2 lists all the characteristics pertinent to this analysis plus any values found in other sections of this report. The first quantity needed to find is the neutral point of the aircraft. This would tell how much the c.g. could move and still keep the plane statically stable. This is important in commercial aviation because of changing configurations, passenger and baggage loadings. Movement beyond the neutral point causes the airplane to be statically unstable. We would like to solve the equation:

$$X_{np}/c = X_{ac}/c - Cm_{\alpha f}/C_{L\alpha w} - \eta V_H C_{L\alpha t}/C_{L\alpha w}(1 - de/d\alpha) \quad (3.2)$$

First of all we can neglect the $(de/d\alpha)$ term (change in downwash angle due to angle of attack).

Table 3.1: C.G. Location for Various Loadings



C.G Formulas:

$$x = \frac{\sum m_i x_i}{\sum m_i}$$

$$y = \frac{\sum m_i y_i}{\sum m_i} = 0.0$$

$$z = \frac{\sum m_i z_i}{\sum m_i} = 1.2092 \text{ ft}$$

Component Weights:

M_1 = fixed equipment + fuselage

$$11014.0 + 8204.0 = 19218 \text{ lb}$$

M_w = wing mass

$$8540.0 \text{ lb}$$

M_L = landing gear mass

$$3190.0 \text{ lb}$$

M_c = empennage mass (including tail mass)

$$1899.0 \text{ lb}$$

M_E = engine mass

$$6304.0 \text{ lb}$$

M_N = nacelles mass

$$1823.0 \text{ lb}$$

Total Component Weight

$$40974.0 \text{ lb}$$

(Table 3.1 continued):

C.G. Location for Various Loading Conditions:

Average weight per person = 170lb x 66 passengers = 11220 lb

Baggage average weight = 3130 lb

Fuel average weight = 14280

$X_{CG} = 50.7509$ ft from the nose

Static margin = 12.39 ft

0.75 passenger and baggage loading at 30 feet from the nose

0.50 fuel weight = 7140 lb

$X_{CG} = 51.5363$ ft

Static margin = 11.604 ft

0.00 passenger and baggage loading

approximately zero fuel

(empty landing weight)

$X_{CG} = 56.865$ ft

Static margin = 6.28 ft

Secondly, the tail efficiency term (η) can be equal to unity since it depends on the position of the tail surface in the wake of the fuselage and the wings. Since we have canard surfaces, no wake influence is seen. Lastly, $C_{m_{\alpha f}}$, pitching moment due to angle of attack on the fuselage, is given as an estimate since it depends on average fuselage section widths and upwash angles which cannot be determined from our basic analysis. With this in mind we find:

$$\begin{aligned} C_{L_{\alpha t}} &= \pi A R_t / 2 = \pi b^2 / 2 S_t \\ C_{L_{\alpha w}} &= \pi A R_w / 2 = \pi b^2 / 2 S_w \end{aligned} \quad (3.3)$$

Then the volume ratio may be determined.

$$V_H = l_t S_t / S_c \quad (3.4)$$

From here it is a matter of putting the values into Equation (3.2). The neutral point was found to be at $X_{NP} = 15.892$ ft. forward from the trailing edge of the wings or 58.1 ft aft of the nose and the aerodynamic center at $X_{ac} = 63.14$ ft from the nose. The center of gravity is located at $X_{c.g} = 50.7509$ ft. aft from the nose for a fully loaded aircraft.

Using the newly found neutral point we can determine the static margin by using the relation:

$$(X_{ac}/c - X_{c.g}/c) = (h - h_n) \quad (3.5)$$

$$(h - h_n) = 12.39 \text{ ft} \quad (3.6)$$

Finally the variation of C_m with angle of attack for various deflections of the canard may be found. Starting with the equation for lift of the tail section plus finding the reference pitching moment and using the already found static margin:

$$C_{L_t} = C_{L_{\alpha t}} V_H (i_t + e_o) \quad (3.7)$$

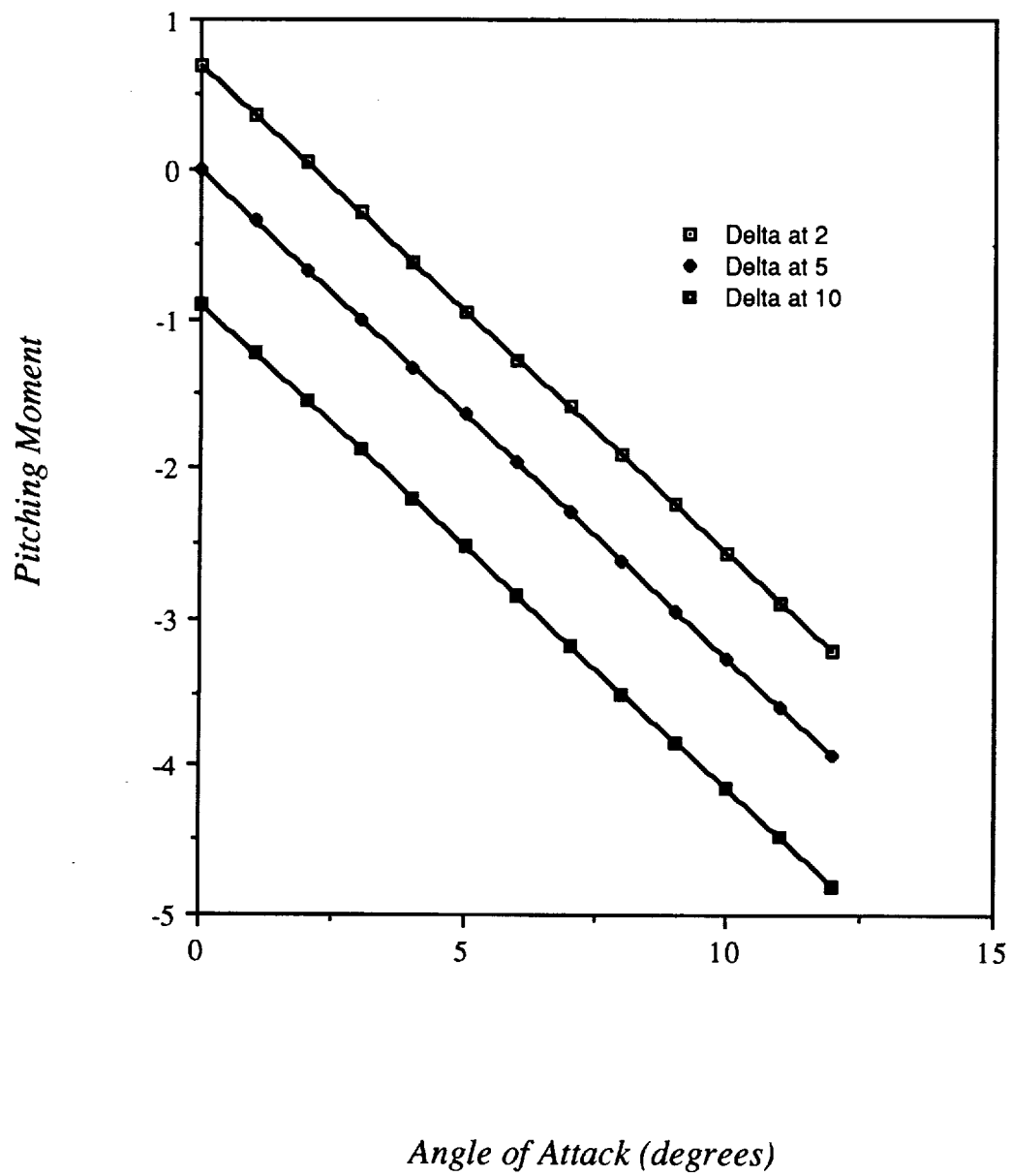


Figure 3.1 Pitching Moment versus Alpha

$$C_{m_{\alpha}} = C_L(h-h_n) - V_H C_{L_t} \quad (3.8)$$

$$C_m = C_{m_0} + C_{m_{\alpha}} \alpha \quad (3.9)$$

This variation can be seen on Figure 3.1 for various control deflections. Mentioning the significance of the canard surface in relation to our design selection, it is free from propulsive interference and thus is better to trim the large moment produced by high lift devices such as our wings. But it also adds to a destabilizing effect on the airplane. This can be counteracted by proper positioning of the center of gravity.

Roll Stability:

Similar to longitudinal stability, the rolling stability can be achieved when a restoring moment is present when the wings are subjected to disturbing forces. The largest contribution to the rolling stability is the dihedral effect and is designated as $C_{l\beta}$. When it is less than zero, the aircraft possess static rolling stability. Relating to our aircraft, it was found that the aircraft was unstable largely due to our wings located underneath the fuselage. So by giving the wings a dihedral angle ($\Gamma=7^\circ$) we attain better rolling stability. In addition, the wings are swept back considerably which gives rise to an increase in the aforementioned dihedral effect.

Dynamic Stability:

The main reason for conducting a dynamic stability analysis is to quantify the aircraft movement in flight; i.e. flight dynamics. In the commercial aviation market, passenger comfort is a prime consideration in customer satisfaction. Also, pilots prefer to fly aircraft that possess good flight characteristics so they do not have to 'fight' the airplane in flight or increase the time necessary to trim flight perturbations. Table 3.1 gives a list of all the longitudinal derivatives found plus the phugoid and short period approximations. Table 3.2 is a list of the equations used to determine the approximate solutions for aircraft dynamic motion.

Table 3.2: Dynamic Stability Derivatives

Initial Conditions:

$u_o=440$ ft/s	$C_D=0.06$	$C_{L\alpha}=10.48$
$W=69045$ lb	$C_L=0.386$	$C_{M\alpha}=-0.33536$
$S=986.68$ ft ²	$C_{Du}=0.0$	$C_{M\alpha}=-0.3$
$b=80$ ft	$C_{Lu}=0.0$	$C_{Mq}=-0.0112$
$c=14.9$ ft	$C_{D\alpha}=0.3$	$I_y=1e6$ slug-ft ²
$q=103.22$ lb/ft ²		
$q_s=101843$ lb		
$q_{sc}=1517460.7$ lb-ft		
$c/2u_o=0.01693$ s		
$u_{om}=27569668$ lb-ft/s		
$u_o I_y=3.993e8$ slug-ft ³ /s		

$X_u=-0.000222$ s ⁻¹	$Z_u=-0.00285$ s ⁻¹	$M_u=0.0$
$X_w=0.000318$ s ⁻¹	$Z_w=-0.00154$ s ⁻¹	$M_w=-0.001274$ ft ⁻¹ s ⁻¹
$X_{\dot{w}}=0.0$	$Z_{\dot{w}}=0.0$	$M_{\dot{w}}=-0.0000193$ ft ⁻¹
$X_q=0.0$	$Z_q=0.0$	$M_q=-0.000288$ s ⁻¹

Phugoid Approximations:

$\omega_{np}=0.01516$ rad/s	$\xi_p=0.007322$
$\lambda_{1,2}=-0.000111 \pm 0.015159i$	
Period= 414.46 s = 6.91 min	
$t_{1/2}=6216.22$ s = 103 min	

Short-Period Approximations:

$Z_{\alpha}=-0.6145$	$M_{\alpha}=-0.5083$	$M_{\alpha}=-0.0077007$
$\omega_{nsp}=0.71295$ rad/s		$\xi_{sp}=-0.006682$
$\lambda_{1,2sp}=0.00476 \pm 0.71293i$		
Period=8.8132 s = 0.147 min		
$t_{1/2}=144.96$ s = 2.42 min		

Table 3.3: Stability Derivative Approximations

<u>Phugoid:</u>	
$\omega_{np}=(-Z_u g/u_o)^{1/2}$	$\xi_p=-X_u/2\omega_{np}$
$\lambda_{1,2}= -\xi_p\omega_{np} \pm i \omega_n(1-\xi^2)$	Period= $2\pi/\omega_n$
$t_{1/2}=0.69/\eta$	
<u>Short-Period:</u>	
$\omega_{nsp}=(Z_\alpha M_q/u_o - M_\alpha)^{1/2}$	$\xi_{sp}=(M_q + M_\alpha + Z_\alpha/u_o)/2 \omega_{nsp}$
$\lambda_{1,2}= -\xi_p\omega_{np} \pm i \omega_n(1-\xi^2)$	Period= $2\pi/\omega_{nsp}$
$t_{1/2}=0.69/\eta$	

The phugoid or long period mode is characterized by changes in pitch, altitude and velocity. In this analysis, if the aircraft was disturbed from its equilibrium, the period of the phugoid motion was found to be 6.91 minutes and the time to half amplitude at 103 minutes. The short-period characteristics were more tolerable with a period at 0.147 minutes and a time to half amplitude equal to 2.42 minutes. To correct the large phugoid oscillations, the lift to drag ratio would have to be reduced, thus decreasing the range. The other alternative is to control the motion by our automatic stabilization computer which would in this case be the preferable choice. As for the short-period characteristics, they are very important as the performance of the airplane is directly related to the frequency of the short-period motion. If the motion is not sufficiently damped or the frequency is too low, the aircraft may become uncontrollable. Although this aircraft is balanced and stable, according to calculations the frequency and damping is indeed too low and must be augmented by the automatic stabilization system.

IV. Structures and Materials

When designing the interior of the fuselage, the number of passengers is an important factor because it directly influences the exterior dimensions, the cabin dimensions, the airline profit and feasibility, and future applications of the aircraft. Therefore, the seating arrangement should be chosen to reflect the needs of the passengers. Passengers want to fly the most economical, comfortable, and safe aircraft available. Based on these factors, the Eagle RTS will accommodate 66 passengers, with a seating configuration of four seats abreast in two rows (See Figure 4.1 and 4.2). With this seating configuration, a sufficient amount of space exists between the aisles and seats to allow for maximum passenger safety and comfort.

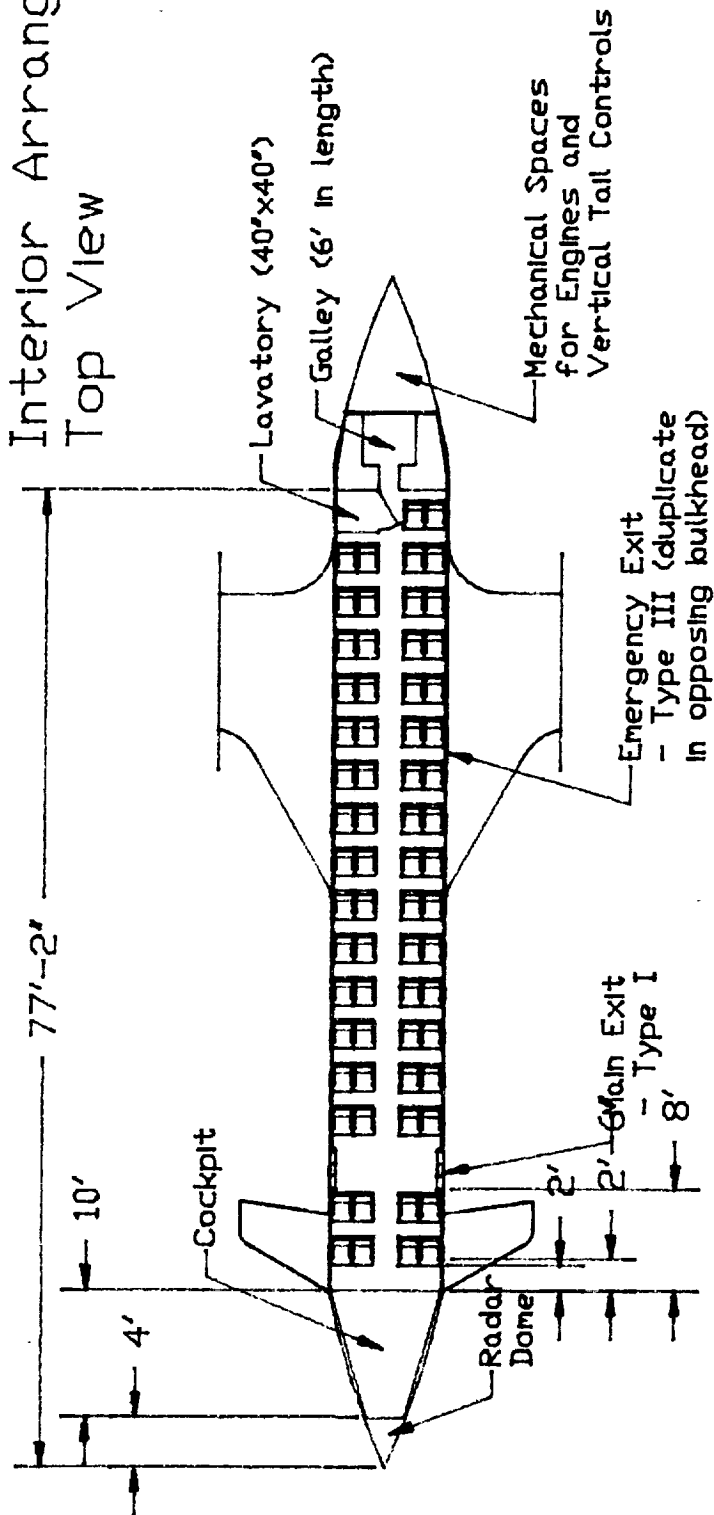
Another important factor in the design of an aircraft is the preliminary weight estimation. Weight directly determines the general configuration, aerodynamic characteristics, and cost of the aircraft. Therefore an accurate estimation of the weight is the first priority in the design of the aircraft. In order to calculate this initial weight, the mission profile of the aircraft must be determined. The Eagle RTS is a regional twin turboprop aircraft with a maximum range of 836 nautical miles capable of transporting 66 passengers. With this type aircraft, the mission profile includes eight phases: Start-up, Taxi, Takeoff, Climb, Cruise, Loiter, Descent, Landing, and Shutdown. By referencing other aircraft with similar mission profiles, an estimated gross take-off weight for the Eagle RTS is determined to be 70,000 lbs⁽¹¹⁾. Gross take-off weight is the weight of the aircraft fully loaded and therefore must include the empty weight, payload weight, crew weight, and the weight of the fuel. This equation can be written,

$$W_{GTO} = W_E + W_{PAY} + W_{CREW} + W_F \quad (4.1)$$

Based on industry studies, passengers on a commercial aircraft have an average weight of 175 lbs. per person and an average baggage weight of 30 lbs per person for short to medium distance flights⁽¹³⁾. For the Eagle RTS, the payload and crew weight was determined to be 14,350 lbs.

In order to calculate the weight of the fuel, the fuel-fraction method will be used. This

Eagle RTS Interior Arrangement Top View



- The seats are spaced 41" front to front.
- The windows are 1' wide and 18" high.

Figure 4.1 Interior Design of the Eagle RTS

Eagle RTS Cross Section of Fuselage

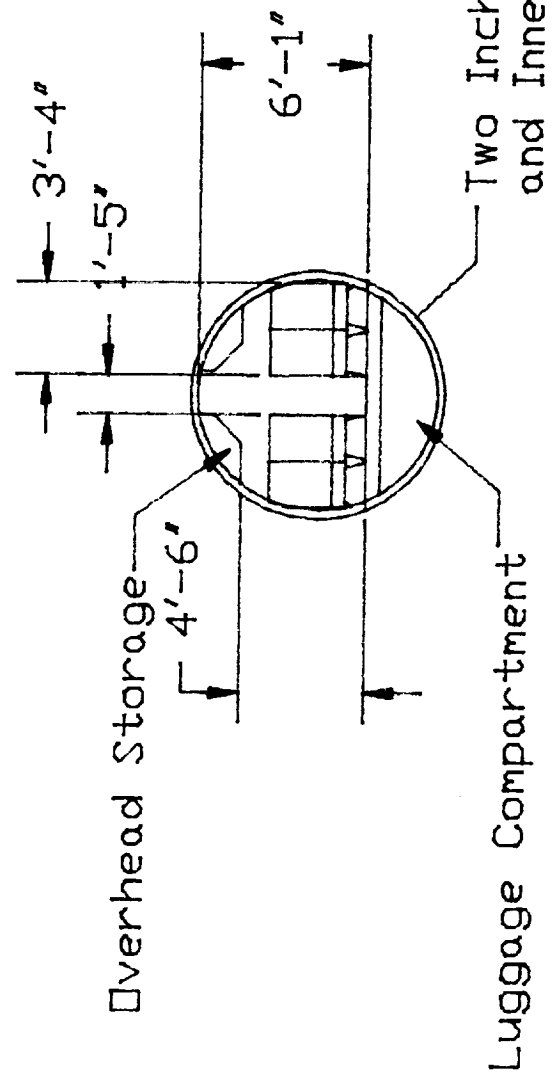


Figure 4.2 Cross Sectional View of the Fuselage

method uses fuel ratios based on previously determined values and is a ratio of the end weight to the beginning weight for each phase of the mission (See Figure 4.3). For the Eagle RTS, the fuel-fraction (FF) was determined to be 0.689 including fuel reserves (See Table 4.1)

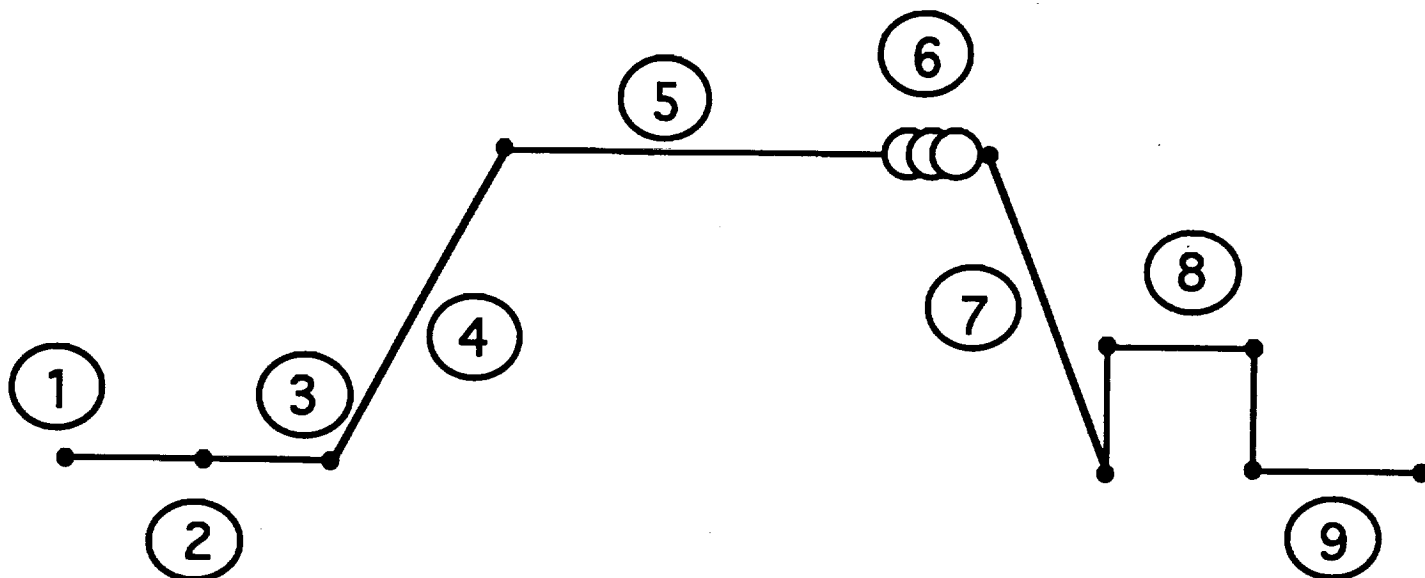


Figure 4.3 Mission Profile for the Eagle RTS

Table 4.1 Fuel Fractions for the Eagle RTS

ID #	PHASE	FUEL FRACTION	RATIO
①	Start-up	$W1/W_{to}$	0.990
②	Taxi	$W2/W1$	0.995
③	Take-off	$W3/W2$	0.995
④	Climb	$W4/W3$	0.980
⑤	Cruise	$W5/W4$	0.820
⑥	Loiter	$W6/W5$	0.967
⑦	Descent	$W7/W6$	0.990
⑧	Landing & Taxi	$W8/W7$	0.992
⑨	Shutdown	—	—

Fuel reserves must be included to adhere to the FAR guidelines and to provide for additional fuel in the case of an emergency. From the fuel-fraction method, the weight of the fuel can be calculated using the equation,

$$W_F = (1 - FF)W_{GTO} = 14,280 \text{ lbs.} \quad (4.2)$$

By using Equation 4.1, the empty weight of the aircraft is determined to be 41,020 lbs. Now that the empty weight is known, the weight of the components can be calculated. The component weight is beneficial because this weight can be used to incorporate the use of composite materials. Using the fraction method of component weights by referencing similar aircraft, the weight of the major component groups can be determined (See Table 4.2).

Table 4.2 Component Weight Estimation and Empty Weight Adjustment

Group	1st Calc	Adjustments	Class I	Composites
Wing	7910	630	8540	7259
Empennage	1750	149	1899	1614
Fuselage	7560	644	8204	6973
Nacelles	1680	143	1823	1549
Landing Gear	2940	250	3190	2711
Power Plant	5810	494	6304	5358
Fixed Equipment	10150	864	11014	9362
Empty Weight	37800	3220	41020	34826

Since composites will be used in limited areas to maximize efficiency and minimize cost, the adjusted empty weight of the Eagle RTS is 40,415 lbs. Composites will be used in areas such as the leading and trailing edges, the inboard and outboard flaps, rudders, elevators, and landing gear doors. Using Equation 4.1, an accurate estimation of the final gross take-off weight is calculated to be 69,045 lbs.

The next phase of the design is to determine the materials used to construct the Eagle RTS. The material selection is based on the maximum loads applied to the aircraft during flight. By utilizing the structural analysis computer program known as MSC/NASTRAN, the resulting stresses, displacements, and forces can be obtained. To illustrate the results processed from NASTRAN, an additional computer program, MSC/XL, can be used. The main wing was modeled using these programs as a cantilever beam with a varying thickness. The wing loading was determined to be 100 lb/ft², with a 1.5 safety factor for normal cruise conditions. The structural limit for maneuvers is a load factor of 4.8 for standard rate turn. The maximum aerodynamic load factor will only be 1.013, therefore the structural limit will never be reached. The results from MSC/NASTRAN reveal that the maximum tensile stress on the upper surface of the wing is 4.68×10^2 psi. Also, the maximum compressive stress is 1.04×10^2 psi was located on the lower surface of the wing. Also, the shear and moment diagrams reveal the maximum allowable loads on the main wing (See Figures 4.4 and 4.5). From these diagrams, main areas where the values for shear and moment are the highest are at the locations where the sweep angle increases.

The materials used for the construction of the Eagle RTS will be an integration of aluminum alloys and composites. The skin and stringers of the upper surface will be constructed of an aluminum alloy which has high tensile stresses allowances. An alloy commonly used in this area is 7075 (Al-Zn), which has an ultimate tensile stress of 72×10^3 psi and a yield stress of 64×10^3 psi⁽¹⁾. For the lower surface of the wing, the alloy 2024 (Al-Cu) will be the main material for the

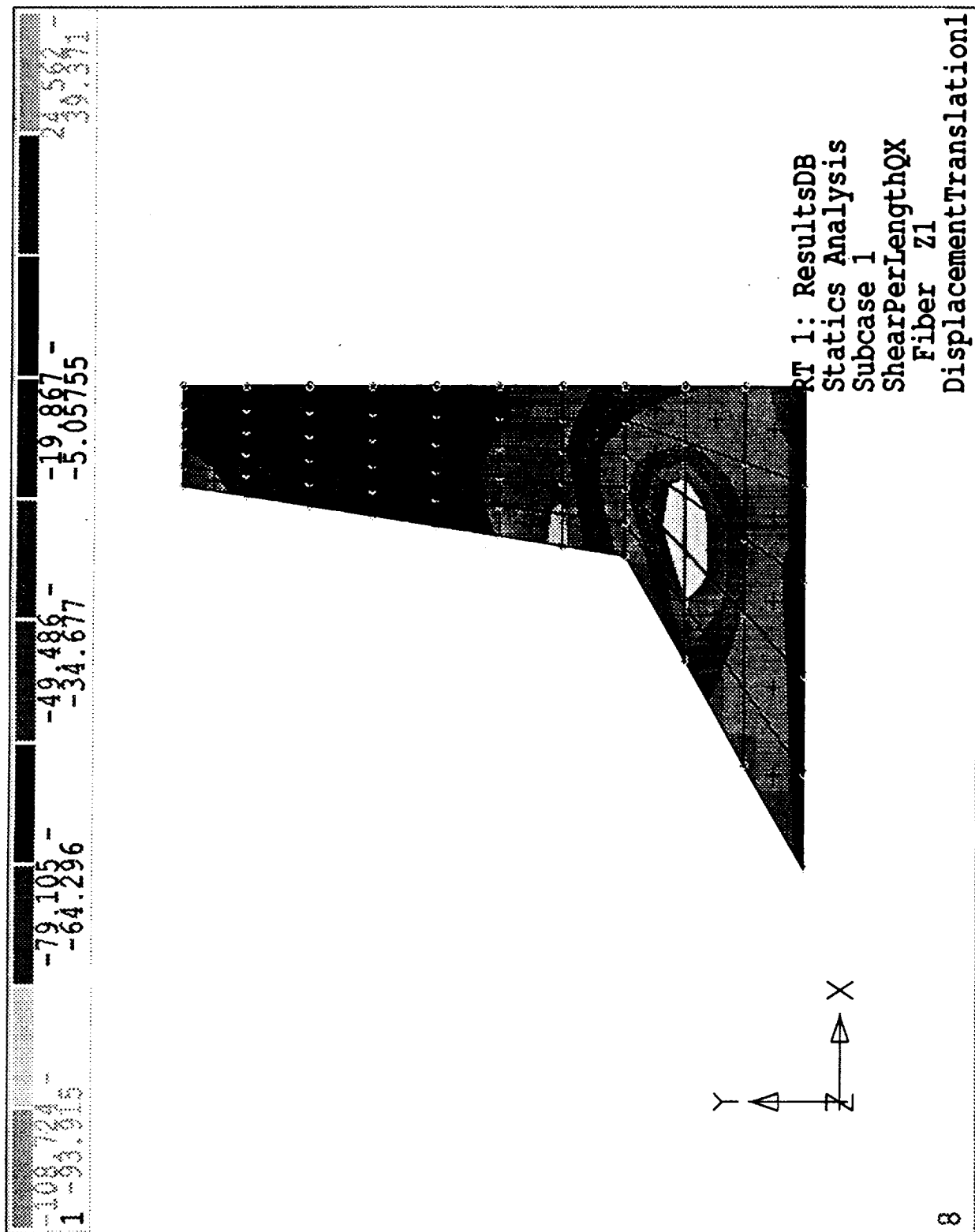


Figure 4.4 Shear Distribution for the Upper Surface on the Main Wing

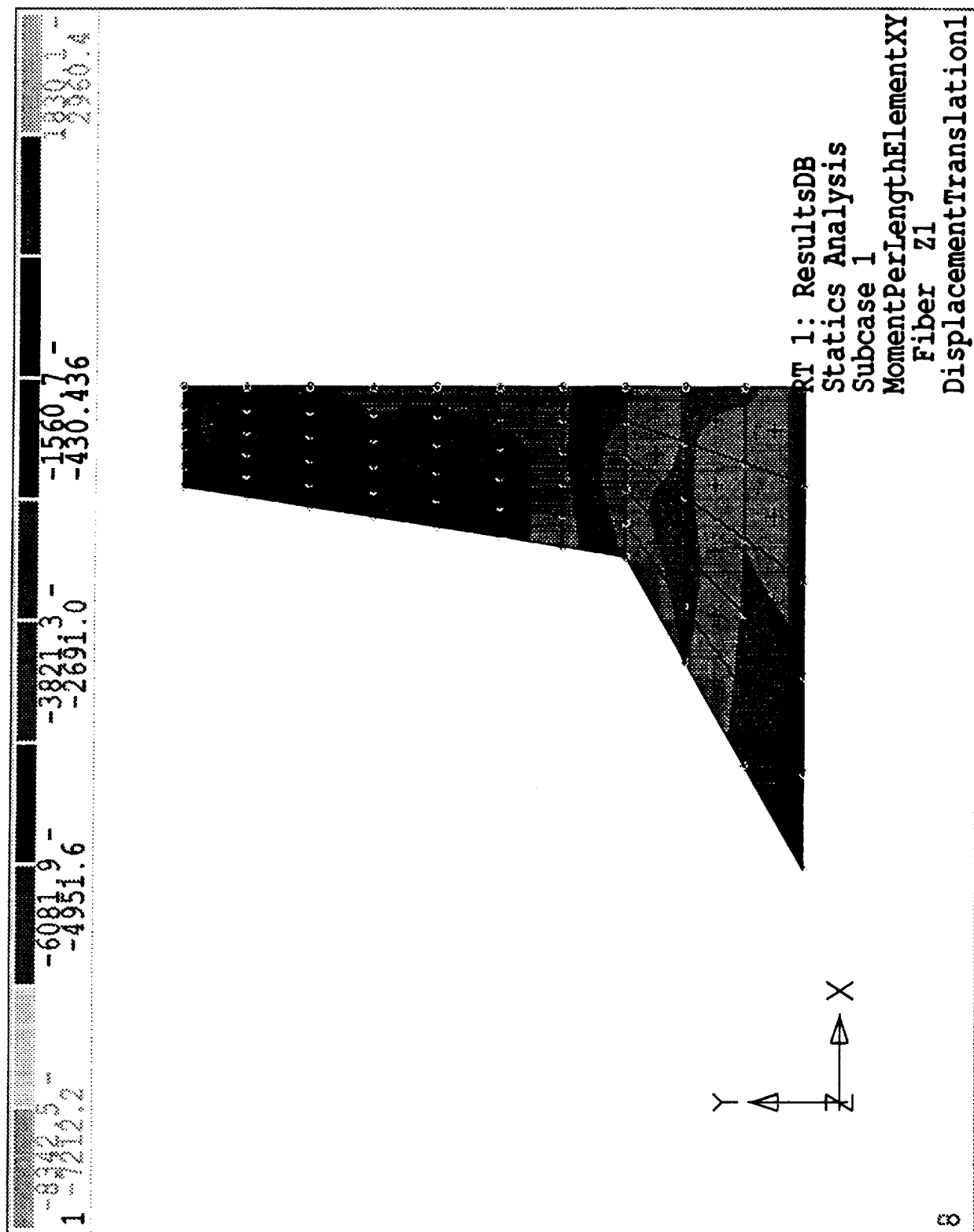


Figure 4.5 Moment Distribution for the Upper Surface on the Main Wing

construction in this area. This alloy exhibits a compressive yield stress of 37×10^3 psi⁽¹⁾. Based on the values determined from the NASTRAN results, the materials used are sufficient to withstand the loads applied during flight.

In order for the Eagle RTS to operate at its maximum efficiency, the weight of the aircraft must be minimized. From the empty weight calculations, the total empty weight was reduced proportionally to the amount of composite materials utilized compared to the aluminum alloys. The purpose for an integration of aluminum alloys and composites is that at the present time, composite materials are too expensive to construct an entire aircraft of this magnitude. Also, most aircraft manufacturers are tooled toward metal⁽¹⁵⁾. Another reason for this integration is that composite materials have not yet demonstrated sufficient strengths with the type of loadings experienced during flight for the commercial industry to totally justify the use of composites in all areas of the construction.

Composites do possess some useful advantages over aluminum alloys. Composite structures demonstrate a weight savings of approximately 25% compared to metals. Another advantage is that composites can be made into any shape and maintain their physical properties. Also, composites have some useful aerodynamic characteristics. They tend to provide a smoother surface for airflow due to the lower surface roughness than metals. Originally, the composites used for the construction were to be Aramid, known commercially as Kevlar. After reviewing the ultimate stresses for both Aramid and graphite/epoxy, it was noted that Aramid had a significantly lower compressive stress than that of graphite. Therefore a combination Aramid will be the primary composite used in areas of high tension, while graphite/epoxy will be used in areas of high compression. A fiberglass composite will be used on the nose cone and the main deck floor panels due to its lower cost and other composites.

As previously stated, aluminum alloys will be the dominant material used on the Eagle RTS. This is mainly because of its "good" strength characteristics, high corrosion resistance, availability, and low cost. While aluminum alloys weigh more than that of composites, aluminum

is the more conservative material. This fact must be considered with a commercial aircraft carrying passengers. Thus, aluminum alloys are more accepted in the commercial aircraft market.

Although based on the NASTRAN results, the stresses in the wing are significantly lower than that of the allowable stresses for the materials used on the wing. Another aluminum alloy, such as aluminum lithium, may be used. Aluminum lithium demonstrates high strength characteristics and weighs less than that of the other aluminum alloys previously stated. Another advantage of this alloy is that it can be manufactured using standard metal techniques, although the raw material cost is greater than the aluminum alloys of copper and zinc.

V. Propulsion

The propulsion system for the Eagle RTS was selected under the consideration that the aircraft is to have a cruise at 25000 feet at a speed of 260 knots (440 feet per second; Mach 0.4). At this speed a turbojet engine would be very inefficient therefore other types of propulsion systems had to be considered. The types of engines that were viable options at speeds near Mach 0.4 were turboprop and turbofan type engines. A.A. Blythe and P. Smith wrote in their American Institute of Aeronautics and Astronautics (AIAA) paper, "Block fuel savings of 25% to 27% are predicted for a M0.7 derivative open rotor aircraft relative to a comparable baseline turbofan powered aircraft. Design range can be increased 45% for equal fuel capacity." ⁽¹⁾ Based on this paper and similar statements in other material a turboprop engine was selected for use on the Eagle RTS.

Once the engine type was selected for the Eagle RTS the engine size needed to be determined. The thrust required for the aircraft was determined from the drag acting on the aircraft in level, unaccelerated flight at the cruise altitude of 25,000 feet. The methods for determining this drag is outlined in the aerodynamics section. The drag acting on the aircraft in cruise configuration is 6300 pounds force. In level, unaccelerated flight the thrust required is equal to the drag on the aircraft. The horsepower required to produce this thrust is calculated from Equation 5.1,

$$Hp = T V / (550 \eta_p) \quad (5.1)$$

where T is thrust in pounds force, V is aircraft velocity in feet per second, and η_p is the propeller efficiency factor. A typical propeller efficiency of 0.8 is assumed for this design. At cruise velocity of 260 knots, 440 feet per second, the horsepower required of the propulsion system is 6300 hp. For a twin turboprop configuration this means 3150 hp. per engine. The highest rated engine currently on the market is the PW 126 produced by Pratt and Whitney, Canada (P&WC). It is cruise rated at 2192 ehp (effective horsepower) at 1200 rpm ⁽⁵⁾. However P&WC is currently testing engines with effective horsepower in the range of 3000 ehp ⁽⁵⁾. The dimensions and weight of the engines for the Eagle RTS can be calculated using the scaling equations from Raymer's

Aircraft Design: A Conceptual Approach ⁽¹⁰⁾ which are stated below in Equations 5.2, 5.3 and 5.4.

$$L = L_{\text{actual}} (SF)^{0.4} \quad (5.2)$$

$$D = D_{\text{actual}} (SF)^{0.5} \quad (5.3)$$

$$W_t = W_{t_{\text{actual}}} (SF)^{1.1} \quad (5.4)$$

where SF is the scaling factor characterized by the equation,

$$SF = T_{\text{required}} / T_{\text{actual}} \quad (5.5)$$

Using the P&WC PW 126 as a base engine the Eagle RTS engine is calculated to have the dimensions as outlined in Table 5.1.

Table 5.1: Engine Dimensions

Dimension	P&WC PW 126	Eagle RTS Engine
Length:	84 inches	97.1 inches
Width:	26 inches	31.2 inches
Height:	31 inches	37.2 inches
Weight:	1060 pounds	1675.6 pounds

Another consideration in the design of the Eagle RTS propulsion plant is the size of the propellers. In his book Daniel Raymer says that when noise is a consideration, as it is in the Eagle RTS, the helical tip speed of the propeller blades should be kept at or below 700 feet per second⁽¹⁰⁾. The propeller disk diameter is calculated using Equations 5.6 and 5.7,

$$(V_{\text{tip}})_{\text{static}} = \pi n d \quad (5.6)$$

$$V_{\text{helical}} = (V_{\text{tip}}^2 + V^2)^{0.5} \quad (5.7)$$

where n is the rotational rate of the engine in revolutions per second, V is the aircraft speed in feet per second, and d is the propeller disk diameter. Using a rotational rate of 1200 rpm (20 rev/sec),

typical for the P&WC PW 100 family of engines, and a cruise velocity of 440 feet per second the propeller disk diameter is calculated to be eight feet eight inches.

The placement of the engines can be seen in Figures 1.2, 1.3 and 1.4. The engine dimensions and engine pylon dimensions can be seen in Figure 5.1. The engines are placed in the position shown due to several reasons. First, the propeller blades require a minimum of nine inches clearance ⁽¹⁾. Secondly, in the unlikely event of a propeller blade being shedded, the blade will not rip through the passenger compartment nor the cockpit. Also, the possibility of damaging the aircraft controls and control surfaces will be remote during such an incident. The final reason behind the engine placement deals with the interaction of the engine air inlet and the canard tip trailing vortices. Despite outward appearances the heart of a turboprop engine is a jet engine and a jet engine requires a smooth, steady flow of air to function. The canards will shed vortices downstream. To minimize the effect of the vortices on the flow into the engines, the engines have been placed as far aft as possible and as high as possible on the aircraft.

A pusher configuration was chosen for the Eagle RTS for several reasons including the fact that the propeller slipstream will not impinge on the aircraft body, therefore reducing induced aircraft drag. Another reason for a pusher configuration is that "the inflow to the propeller keeps the air flow attached to the tailcone" thereby reducing drag further ⁽¹⁰⁾. Finally, the cabin noise is reduced by placing the engines and propellers behind the passenger compartment.

Eagle RTS

Engine Dimensions

- length: 97.1 inches
- width: 31.2 inches
- height: 37.2 inches
- weight: 1675.6 pounds

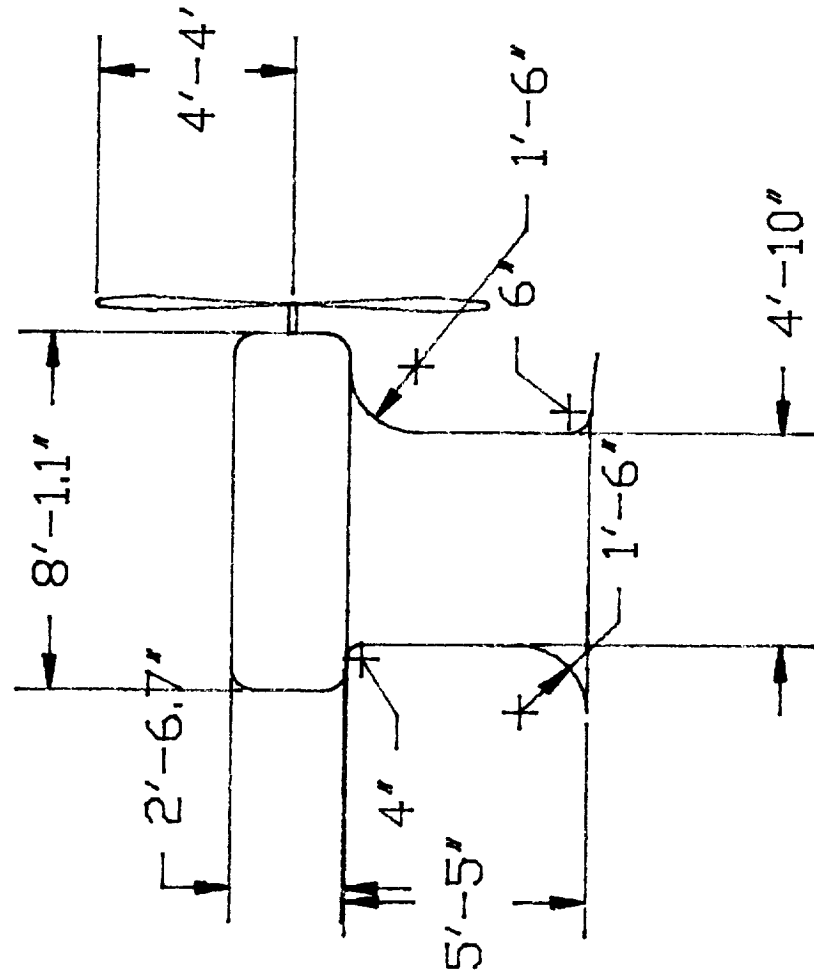


Figure 5.1 Engine Dimensions

VI. Cost Analysis

The determination of total costs are based on calculations from Raymer's Aircraft Design.⁽¹⁾ Where the following variables are:

W_E = empty weight = 40,415 lbs

V = maximum velocity = 290 knots

Q = quantity produced = 500

FTA = number of flight test articles = 2

C_{ENG} = engine cost = \$186,000

C_{av} = avionics cost = \$1,000,000

The engineering hours include the design and analysis of the aircraft. Most of the time is performed during the research and development phase of the operation. The amount of engineering hours is calculated using

$$\text{Eng hours} = 4.86 W_E^{0.777} V^{0.894} Q^{0.163} = H_E = 8,076,733 \quad (6.1).$$

The amount of time necessary to prepare the aircraft manufacturers plant for tooling is determined by using the following equation,

$$\text{Tooling hours} = 5.99 W_E^{0.777} V^{0.894} Q^{0.263} = H_T = 18,532,044 \quad (6.2)$$

The amount of time needed to assemble the entire quantity produced is calculated by

$$\text{Mfg hours} = 7.37 W_E^{0.82} V^{0.454} Q^{0.641} = H_M = 31,102,898 \quad (6.3)$$

The quality control hours is the amount of time needed to ensure that the product meets the design specifications and is determined using the equation,

$$\text{QC hours} = (0.133)H_M = H_{QC} = 4,136,685 \quad (6.4)$$

The development-support cost are those cost such as mockups, simulators, and various tests.

These value can be calculated using the following equation,

$$\text{Devel. Cost} = 45.42W_E^{0.63}V^{0.822} = C_D = \$3,832,305. \quad (6.5)$$

Flight test cost cover all expenses to receive a certification from the FAA. This includes the number of flight tests necessary to demonstrate airworthiness. The flight test costs is determined by,

$$\text{Flight Test Cost} = 1243.03W_E^{0.325}V^{0.822}FTA^{1.21} = C_F = \$9,548,494 \quad (6.6)$$

The manufacturing materials cost is the total cost of the raw material needed to assemble the aircraft, which includes the amount of aluminum alloys and composites. This value is calculated from the following equation,

$$\text{Mfg Material Cost} = 11.0W_E^{0.921}V^{0.621}Q^{0.799} = C_M = \$932,490,882 \quad (6.7)$$

The total cost of the aircraft can now be estimated using the following equation,

$$\text{RDT\&E} + \text{flyaway} = H_ER_E + H_TR_T + H_MR_M + H_QR_Q + C_D + C_F + C_M + C_{ENG}N + C_{AV}N \quad (6.8)$$

where the hourly rates for engineering, tooling, manufacturing, and quality control are estimated in U.S. dollars⁽¹⁾ Using this equation, the total cost of the Eagle RTS project was determined to be 5.1 billion dollars. The selling price including an investment factor for the Eagle RTS will be 10.2 million dollars. At this price, the Eagle RTS will be competitive with other aircraft in the regional commercial market.

The direct operating costs (DOC) of the Eagle RTS is divided into three sections: fuel, crew salaries, and maintenance(See Figure 6.1). The fuel cost was calculated by determining the amount of fuel burned per year. Assuming that the Eagle RTS averages 4000 flight hours per year, the fuel cost is 1.5 million dollars per 1000 flight hours. The crew salaries is estimated to be 209,000 dollars of the DOC. The maintenance costs per year can be estimated by determining the maintenance hours required per flight hour. The maintenance cost per year was calculated to be 30,000 dollars. The majority of the maintenance costs are due to the type of engine selected for the Eagle RTS. The remaining cost of the DOC is the depreciation and insurance value. Therefore the direct operating cost of the aircraft per 1000 flight hours was determined to be 1.04 million dollars.

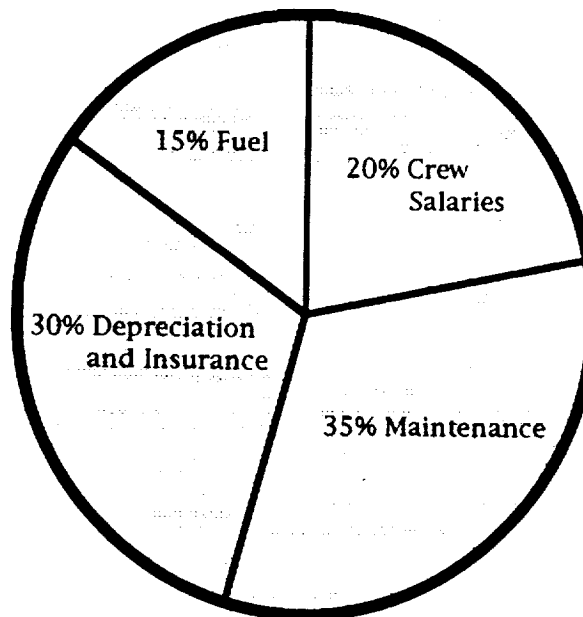


Figure 6.1 Direct Operating Costs

VII. Management Plan

The Eagle RTS will have an expected operational lifetime of 60,000 flight hours or approximately 15 years. The first phase of the production of this aircraft is the research and design, which will consist of two years (See Table 7.1). This phase includes time for such areas as engineering, development, and tooling time. The manufacturing timeline of the Eagle RTS will be three years because most of the major aircraft manufacturers already possess the knowledge and equipment to produce aircraft which integrate aluminum alloys and composite materials. A total of 500 aircraft will be constructed in this phase. As stated earlier, the expected lifetime is 15 years, but could be increase due to the economic and safety features represented in this aircraft.

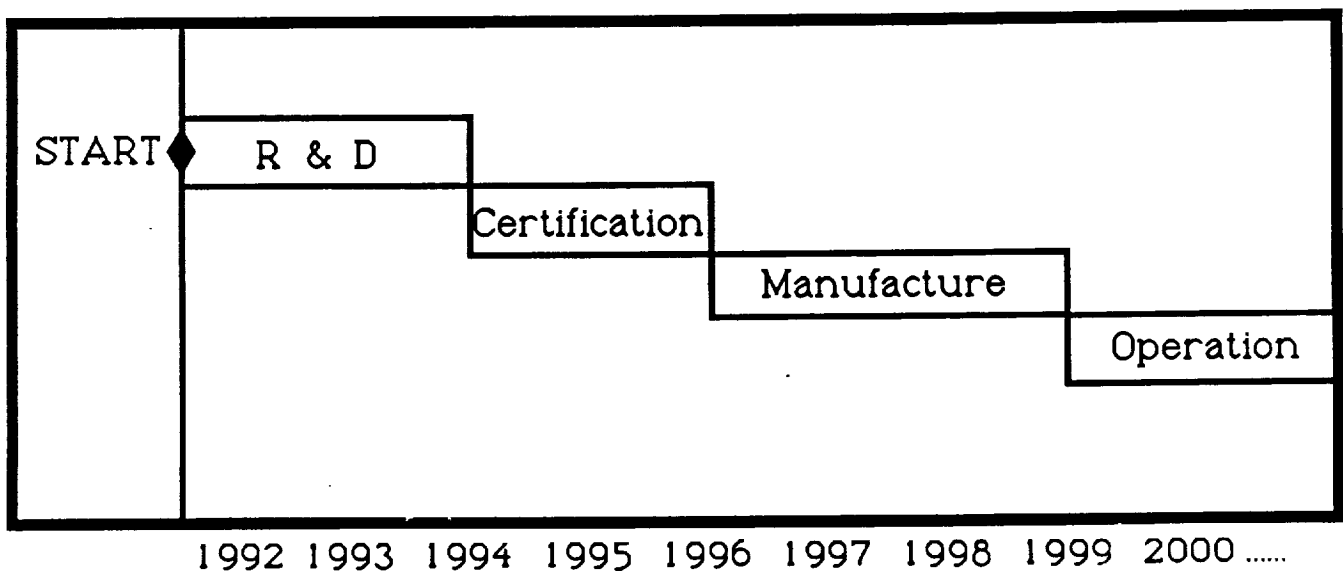


Table 7.1 Management Timetable

Discussion

One possible question that will arise is that of the effect of canard trailing vortices on the engine and overall performance of the aircraft. In the previous section, aerodynamics, this topic was covered and stated that the most efficient way to minimize these effects was through placing the engines and main wing as far above and aft as possible. This technique is only a temporary solution to the problem. Only time and research will provide a true answer to this problem yet, for the Eagle RTS the advantages in using a canard greatly outweigh the disadvantages.

In conducting a stability analysis, a few problems arose, namely getting the center of gravity forward enough to make the aircraft stable. But moving the wings forward helped this problem as well as balancing the aircraft and this works in conjunction with the automatic stabilization systems on-board. Having wings as large as ours gives rise to a very large moment and they have to be moved forward to counteract this effect. In roll stability, we had to move the wings up a dihedral angle of seven degrees to help in this stability problem. The flow around the fuselage tends to sideslip the aircraft and this dihedral effect helps control that problem. In dynamic analysis of this aircraft the short-period frequency and damping is too low which could lead to an uncontrollable aircraft. The way in which this could be controlled is with the automatic systems where they will give enough damping to make the airplane flyable. On the performance side, our range came out significantly better than our initial assessment and the endurance is competitive to the specified needs.

In terms of the weight of the aircraft, these values represent preliminary design estimates. A more detailed weight can be obtained once all of the external dimensions and aerodynamic characteristics are precisely known. Due to time limitations and constant adjustments in the configuration to account for stability, performance, and propulsion, an estimate of the empty weight and gross take-off weight can only be determined at this time.

Another area in which the design could be improved is with the computer structural design.

The main wing was modeled on MSC/XL as a cantilever beam. A three-dimensional design would provide a more realistic model of the forces on the main wing. Although, these initial values provide preliminary information which would allow the design team can make alterations in final design of the Eagle RTS.

Summary and Conclusions

The Eagle RTS was developed to meet a specific gap in the commercial aircraft industry. It was designed to carry passengers between metropolitan areas while avoiding the congested hub airports. The aircraft is designed to maximize performance while minimizing operational costs.

As previously stated, one of the primary considerations in designing the Eagle RTS was one of cost. The Eagle RTS was designed using proven leading edge technology to allow for an advanced aircraft while holding down the development costs.

The Eagle RTS has several interesting features such as computer controlled avionics which will allow the aircraft to continuously update and adjust its trim configuration for optimal stability. Also the aircraft computer system will calculate the optimal engine fuel flow to maintain peak engine efficiency. Another interesting feature of the Eagle RTS is that the aircraft aerodynamics were developed assuming non-laminar flow due to unclean flight surfaces and the like. This assumption is made so the consumer will have reliable fuel consumption and operational cost estimates for the Eagle RTS. If the aircraft is cleaned frequently the fuel consumption and operational costs will be minimized, thus the consumer can only benefit.

One distinguishing feature of the design of the Eagle RTS was that the structural analysis was done using MSC/XL and NASTRAN. This allowed for the maximum possible precision in the stress analysis at this stage of the design process. Based on the values determined from the NASTRAN analysis, the stresses located on the wing surfaces are significantly lower than the allowable stresses for the materials used.

The analysis of the Eagle RTS design could have been enhanced by several things. The aerodynamics could have been more tightly optimized if research on the effects of canard tip vortices on lifting surfaces was available. The evaluation of the aircraft performance would have been more precise if an engine of the required power levels had been available and values for a theoretical engine did not have to be used. However, the overall design of the Eagle RTS was well researched and will fill the void that exists in the regional transport market.

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Appendix A

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c Paul Lemke
c Feb. 13, 1992
c
c This program calculated drag polars for aircraft based on the
c methods in Jan Roskam's "Methods for Estimating Drag Polars
c of Subsonic Aircraft"
c
c Assume Subsonic Mach numbers,  $M \leq 0.6$ 
c
c Equation:  $C_d = (C_{do})_{wb} + (C_{do})_v + (C_{do})_h + (C_{di})_{wb} + C_{d \text{ misc}}$ 
c where  $C_d$  = drag coefficient
c  $(C_{do})_{wb}$  = zero lift drag coeff of a wing body combination
c  $(C_{do})_v$  = zero lift drag coeff of vertical tail(s)
c  $(C_{do})_h$  = zero lift drag coeff of horizontal tail
c  $(C_{di})_{wb}$  = induced drag coeff of a wing body configuration
c  $C_{d \text{ misc}}$  = incremental drag coeff due to miscellaneous causes
c
c
c INITIALIZATION
  IMPLICIT DOUBLE PRECISION (A-Z)
  INTEGER N,wsec
  DIMENSION mac(10), tc(10), xt(10), SSECREF(10), SWET(10)
  DIMENSION CFW(10), RLS(10)
  PI=3.14159265359d0
  fd=0.0
  db=0.0
10  FORMAT(' *****')
20  FORMAT(' **')
30  FORMAT(' **          Drag Polar Calculator')
40  FORMAT(' **          for subsonic aircraft with')
50  FORMAT(' **          Mach<0.6')
60  FORMAT(' ')
  WRITE(*,10)
  WRITE(*,20)
  WRITE(*,30)
  WRITE(*,40)
  WRITE(*,50)
  WRITE(*,20)
  WRITE(*,10)
  WRITE(*,60)
160  FORMAT(' Enter the Aircraft Fuselage Length: ')
  WRITE(*,160)
  READ(*,*) lb
170  FORMAT(' Enter the Maximum Width of the Aircraft Fuselage: ')
  WRITE(*,170)
  READ(*,*) fwidth
180  FORMAT(' Enter the Maximum Height of the Aircraft Fuselage: ')
  WRITE(*,180)
  READ(*,*) fheight
  BCSAREA=PI/4.0d0*fwidth*fheight
  fd=DSQRT(BCSAREA/0.7854d0)
200  FORMAT(' Enter the Total Wetted Area of the Body: ')
  WRITE(*,200)
  READ(*,*) BSWET
190  FORMAT(' Enter the Diameter of the Fuselage Base, 0 if tapers to

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& a tip: ')
WRITE(*,190)
READ(*,*) db
WRITE(*,*) 'Enter the Wing Reference Area'
READ(*,*) SREF
WRITE(*,60)
70  FORMAT(' Enter the number of sections to break wing into: ')
    WRITE(*,70)
    READ(*,*) WSEC
c
c (Cdo)wb
80  FORMAT(' Calculating Cdo wb')
    CFW(1)=0.00238D0
    CFW(2)=0.00247D0
    RLS(1)=1.09D0
    RLS(2)=0.84D0
    CFB=0.0019D0
    RWB=0.975d0
    DO 110 N= 1,WSEC
        WRITE(*,60)
90  FORMAT(' Wing Section ',I2)
        WRITE(*,90) N
100  FORMAT(' Enter Mean Aerodynamic Chord: ')
        WRITE(*,100)
        READ(*,*) mac(N)
120  FORMAT(' Enter Thickness Ratio: ')
        WRITE(*,120)
        READ(*,*) tc(N)
150  FORMAT(' Enter the chordwise position of the maximum thickness: ')
        WRITE(*,150)
        READ(*,*) xt(N)
        IF(xt(N).GE.(0.3*MAC(N))) THEN
            L=1.2D0
        ELSE
            L=2.0D0
        ENDIF
130  FORMAT(' Enter Wing Section Reference Area: ')
        WRITE(*,130)
        READ(*,*) SSECREF(N)
140  FORMAT(' Enter Total Wing Section Wetted Area: ')
        WRITE(*,140)
        READ(*,*) SWET(N)
        CDPANELI=CFW(N)*((1.0D0+L*TC(N)+100.0D0*TC(N)**4)*RLS(N)
        &*SWET(N)/SSECREF(N)
        CDPANEL=CDPANEL+CDPANELI
110  CONTINUE
        CDFB=CFB*(1.0d0+(60.0d0/(lb/fd)**3.0d0)+0.0025d0*(lb/fd))*(BSWET/
        &BCSAREA)
        CDB=0.029*(db/fd)**3/DSQRT(CDFB)
        CDOWB=(CDPANEL+CFB*(1.0D0+(60.0D0/(LB/FD)**3.0D0)+0.0025D0*LB/FD)
        &*(BSWET/SREF))*RWB+CDB*(BCSAREA/SREF)
        WRITE(*,80)
        WRITE(*,*) CDOWB
* (Cdo)v
    CFV=0.0075d0

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      RLSV=0.75D0
      WRITE(*,60)
      WRITE(*,*) '** Calculating for Vertical Tail **'
      WRITE(*,100)
      READ(*,*) macv
      WRITE(*,120)
      READ(*,*) TCV
      WRITE(*,150)
      READ(*,*) XTV
      IF(XTV.GE.(0.3*MACV)) THEN
        LV=1.20D0
      ELSE
        LV=2.0D0
      ENDIF
210  FORMAT(' Enter the Total Wetted Area of Vertical Tail')
      WRITE(*,210)
      READ(*,*) SWETV
      CDOV=CFV*(1.0D0+LV*TCV+100.0D0*TCV**4)*RLSV*SWETV/SREF
      WRITE(*,*) 'Cdo v'
      WRITE(*,*) CDOV
* (Cdo)h
      CFH=0.0022d0
      RLSH=0.75D0
      WRITE(*,*) '** Calculating for Horizontal Tail **'
      WRITE(*,100)
      READ(*,*) mach
      WRITE(*,120)
      READ(*,*) TCH
      WRITE(*,150)
      READ(*,*) XTH
      IF(XTH.GE.(0.3*MACH)) THEN
        LH=1.20D0
      ELSE
        LH=2.0D0
      ENDIF
220  FORMAT(' Enter the Total Wetted Area of Horizontal Tail: ')
      WRITE(*,220)
      READ(*,*) SWETH
      CDOH=CFH*(1.0D0+LH*TCH+100.0D0*TCH**4)*RLSH*SWETH/SREF
      WRITE(*,*) 'Cdo h'
      WRITE(*,*) CDOH
* (Cdi) wb
      N=0.00066667D0
      OMEGA=5.4554472559D-4
      E=0.7d0
      WRITE(*,*) '** Calculating Induced Wing Body Drag **'
230  FORMAT(' Enter the Coefficient of Lift for the Main Wing: ')
      WRITE(*,*) 'Enter the Wing Twist, positive for wash-in: '
      READ(*,*) THETA
      WRITE(*,*) 'Enter the Wing Span: '
      READ(*,*) span
      ar=span**2/sref
      nu=0.69d0
      cdc=1.2d0
      WRITE(*,*) 'Enter the Body Reference Area: '

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      READ(*,*) Sbref
      WRITE(*,*) 'Enter the Body Planform Area: '
      READ(*,*) Sp
      WRITE(*,*) 'Enter the Aspect Ratio: '
      READ(*,*) ar
      Sb=BCSAREA-pi*(db/2)**2
* Miscellaneous Drag Contributions
* landing gear drag
* flaps drag
* windsheild drag
      CDWINDSH=0.078*BCSAREA/SREF
* nacelle drag, neglect interference drag for turboprops
      dcl1=-3.0d0
      WRITE(*,*) 'Enter the Engine Pylon Chord Length: '
      READ(*,*) cn
      WRITE(*,*) 'Enter the Engine Nacelle Width: '
      READ(*,*) nwidth
      WRITE(*,*) 'Enter the Engine Nacelle Height: '
      READ(*,*) nheight
      NCSAREA=nwidth*nheight
      dn=DSQRT(NCSAREA/0.7854D0)
      WRITE(*,*) 'Enter the Angle of the Nacelle to Pylon Centerline: '
      READ(*,*) eta
      dcl2=-0.056d0*eta
      Cdnacel=0.036d0*cn*dn/SREF*(dcl1+dcl2)**2
* speed break drag, ignored
* total misc drag
      Cdmisc=CDWINDSH+CDNACEL
      WRITE(*,*) 'Total Miscellaneous Drag'
      WRITE(*,*) CDMISC
* DRAG POLAR
      OPEN(UNIT=1,FILE='DRAGPOL.DAT',STATUS='NEW')
      WRITE(*,*) 'Enter the Angle of Attack of the Main Wing Relative
&to the Fuselage: '
      READ(*,*) WALPHA
      WRITE(*,*) 'Enter the Lowest Angle of Attck to Compute: '
      READ(*,*) LALPHA
      WRITE(*,*) 'Enter the Highest Angle of Attack to Compute: '
      READ(*,*) HALPHA
      ALPHA=LALPHA-WALPHA-1.0d0
      WRITE(*,*) 'Enter All Angles of Attack Relative to the Wing.'
900   ALPHA=ALPHA+1.0D0
      BALPHA=ALPHA*PI/180.0D0
910   FORMAT(' Enter the Coefficient of Lift at ',F5.0)
      WRITE(*,910) ALPHA+WALPHA
      READ(*,*) CLWING
      CDLW=CLWING**2/(PI*AR*E)+CLWING*THETA*2.0D0*pi*N+(THETA*2.0D0*pi)
&**2*OMEGA
      cdalphab=2.0d0*balpha**2*Sb/Sbref+nu*cdc*Sp/Sbref*balpha**3
      Cdiwb=Cdlw+cdalphab*Sbref/SREF
      Cd=Cdowb+Cdov+Cdoh+Cdiwb+Cdmisc
      write(*,*)'Drag      Angle of Attack'
      WRITE(*,*) Cd, ALPHA
      WRITE(1,*) ALPHA,CD,CLWING
      IF(ALPHA.LE.HALPHA-WALPHA) THEN

```